Quantifying the use of firewood as a source of energy in North West Province: A case study for Matlwang

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Dissertation accepted in fulfilment of the requirements for the degree *Master of Science in Environmental Sciences* at the North-West University

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Graduation May 2021

26720019

DECLARATION

I, **Funanani Grace Lavhelani**, declare that this dissertation submitted for the degree of Master of Science in Environmental Sciences at the North-West University is my own work, and that it has not been submitted previously for any degree or examination at any other University, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

Funanani Grace Lavhelani 02 December 2020

This dissertation is dedicated to the special people in my life:

especially my parents, Mr NP Lavhelani and Dr NP Lavhelani,

my brothers, Phathutshedzo and Riphuluse,

and

my sister, Vhulenda.

To my brothers and sister, may our living God of Mount Zion give you strength to reach a higher level than I have achieved so far.

May our living God of Mount Zion bless all your future plans.

ACKNOWLEDGEMENTS

Glory and thanks to the living God of Mount Zion, for through Him I can do all things.

I am greatly indebted to my supervisor, **Prof. S.J. Piketh**, for his financial support, guidance and supervision.

I would also like to thank my mother, **Dr N.P Lavhelani**, for the motivation and encouragement throughout the duration of this study.

Thank you to **Ms Jeannette Menasce** for proofreading, correcting and editing this dissertation.

PREFACE

Globally, the use of firewood for cooking and heating, remains popular, be it by using traditional stoves or open fires. Most of these stoves are fired with biomass fuels (such as wood, branches or twigs) (Marufu *et al*., 1997). “It is estimated that 70 % of households in developing countries use fuels such as wood, dung and crop residues for cooking and heating”. Heltberg (2004) stated that energy use depends on its accessibility and availability as well as costs. Given the extreme poverty in developing countries and the high cost of fossil-fuel products, firewood remains the most used fuel in rural areas, whereas charcoal is utilised mainly in large cities. In Abidjan, for example, 90 % of the population use charcoal in their households. In most cases, the living conditions of the poor are also worsened through the health impacts and quality of life associated with burning traditional biomass fuels. The increase in quality and convenience of fuels is usually accompanied by higher energy costs, leading to a trade-off between quality and cost and, as a result, the use of firewood, dung and crop waste is prevalent among poor households, while households with higher incomes move to the use of electricity and Liquid Petroleum Gas (LPG).

Makonese, Ifegbesan and Rampedi (2018) also suggested that firewood use is driven not only by economics but also has a psychological and behavioural component. There are native and socio-cultural perceptions attached to the use of different energy sources. Hence, the continuous use of firewood, though the communities have access to electricity. “Firewood remains a primary energy resource for cooking and heating among electrified South African households, in rural communities” (Uhunamure, Nethengwe & Musyoki, 2017). According to Makonese *et al*. (2018), firewood “is the preferred energy resource for cooking and heating in most southern African countries, including Angola, Lesotho, Malawi, Namibia, Swaziland, Zambia and Zimbabwe”.

The World Health Organisation (WHO) (2000), started an initiative to promote households to switch from traditional and historically used fuels as primary energy carriers, to more modern options which include more efficient and cleaner burning stoves in a bid to reform the energy sector by using innovative technology. In some countries (for example, Brazil) this has been effective, whereas in most developing countries the outcomes have not been promising. The aim of this study was to quantify the use of firewood as a source of energy in the township of Matlwang, in the North West Province of South Africa.

The results of the study show that 86 % of households in the township use firewood for cooking and heating. The sources of firewood for households and vendors of Matlwang were found to be Kgapamadi, Kgabaesetswe and Tshopane hills. Among these three collection points, the Kgapamadi hill is the preferred site for households and vendors as it is considered safe and is closer to the township. Vendors in the township collect firewood using donkey carts. They reported that the distance is relatively short and convenient for their donkeys and does not cause harm to the donkeys as they reach home without dragging their hooves. Kituyi *et al*. (2001a, 2001b) opined that “as long as the load is correctly placed on the back of the animal and a proper loading system is used, an average donkey of approximately 11 hands high or 160 kg can carry up to 50 kg (8 stone) on its back”. Tree species preferred for firewood in the township were also identified. The households preferred three tree species: Mooka (*Vachellia karroo*), Moumo (*Ficus sur*) and Mmilo (*Aphloia theiformis*) firewood for both cooking and heating. Among these three tree species, the Mooka species is the favourite tree species, with 80 % of households using it for household cooking and heating because of its abundance and ability to burn for long periods of time. The households reported that wood is their most important source of energy as they cannot afford to buy electricity, paraffin and gas. Some of the households (28%) indicated that their households were not electrified and, as a result, they did not have access to electricity.

The emissions from the burning activities in Matlwang have been estimated from the mass of wood burned in each household in the summer and winter season. The results indicate that the households use approximately 20 (± 2.8) to 35 (± 7.1) kg.wood.household^{-1}.day^{-1} or 4.8 (± 2.4) to 7.8 (± 2.9) kg.wood.person^{-1}.day^{-1} in summer and winter, respectively. The resulting emissions for the township of CO_2, CO, NO and CH_4 are 894 (± 328), 85 (± 31), 1 (± 0.3) and 3 (± 1) t.annum^{-1}. From a national perspective, this shows that individuals in Matlwang emit far less than the per caput emissions for South Africa.

STRUCTURE OF THIS DISSERTATION

This dissertation is divided into six chapters. A short description of each chapter is given below.

Chapter 1: Introduction

This chapter gives a brief introduction and motivation for this study by providing a background of the state of domestic burning at a national and global scale. The research questions and objectives of the study are also outlined in this chapter.

Chapter 2: Literature review

This chapter discusses the importance of firewood as a resource for many rural communities, the sources of firewood, preferred species being harvested and the environmental implications at the current rate of extraction. The chapter also covers a detailed description of all fuels burnt and their associated pollutants and greenhouse gases that are emitted from the combustion processes. This chapter also discusses the climatic effects and the health risks associated with the resulting emissions.

Chapter 3: Research methodology

This chapter provides a detailed description of the study site at which this research was conducted. It describes the processes and methodologies involved in conducting this research as well as the materials and instrumentation that were used.

Chapter 4: Results

This chapter focuses on the results generated from the field study. The chapter starts by profiling the households, and presents the fuel types utilised in Matlwang, the types of cooking devices, the sources of firewood in Matlwang, the burning patterns and the mass of firewood consumed in summer and winter in the households of Matlwang. Finally, quantification and estimations of the emissions produced by households in Matlwang are presented.

Chapter 5: Discussion

This chapter discusses results of the field study, and their potential impact.

Chapter 6: Conclusions and recommendations

This chapter provides a summary of the findings and the conclusions made based on the objectives of the study. It also provides recommendations based on the limitations of the study.

The **References** follow **Chapter 6**.

ABSTRACT

The aim of the current study was to quantify the use of firewood as a source of energy in Matlwang, a small township in the North West Province of South Africa. A mixed method was used to collect data for the study. The rationale for adopting it was to garner unique perspectives on the dynamics of solid-fuel usage as well as emissions produced from a predominantly wood-burning township. Methods for sourcing the required data included face-to-face interviews with one member from each of 50 households, structured questionnaires, and observations. The questionnaires were administered to fifty households that were selected randomly in the township. In addition to the interviews and questionnaires, during the summer and winter of 2017, twenty households were issued scales to weigh the firewood they burnt daily. These data provided the consumption of firewood in the township as well as formed the basis for calculations of emissions during summer and winter. The total household and township emissions estimates for CO_2, CO, NO and CH_4 have been calculated.

Of the households in the township, 86 % used firewood for cooking and heating. The remaining 14 % used electricity, gas (LPG) or paraffin. The households use firewood in both seasons as their only source of primary energy. The results of this study show that the unemployment rate, poverty, culture, age, lack of access to electricity and readily available firewood are reasons the households continue to use firewood as a source of energy. About 64 % of households in the township stated that they used firewood because of poverty. Most households in the township reported that they did not have jobs, which meant they could only afford to collect or buy firewood because it is cheaper than purchasing electricity, paraffin, and LPG. The majority of households advised that collecting firewood is convenient since it does not require money for either the wood or transportation to get it back to the house. Households that are unable to collect their own wood purchase the wood from vendors who collect it. A "load" of wood (namely, one "donkey cart" of approximately 50 kg) is sold to households for between ZAR 120 and ZAR200, depending on the type/quality of wood purchased. The households indicated that they had three preferred sites from which they collected firewood, namely, Kgapamadi, Kgabaesetswe and Tshopane hills. Kgapamadi was the preferred site for the households and vendors interviewed. The region surrounding Matlwang is clearly at risk of significant environmental damage as a result of vegetation clearing. This is exacerbated by the fact the three preferred types of wood collected were all indigenous species: "Mooka", "Moumo" and "Mmilo". In addition to the

economic reasons for burning firewood, studies have indicated that practising culture and tradition may also influence the high consumption of firewood (Andreae *et al.,* 1996).

All the households in the township burnt wood three times daily: in the morning (04:00 to 10:00), afternoon (12:00 to 16:00) and evening (18:00 to 22:00). The entire township burns on average 399 kg of firewood.day^{-1} in summer and 702 kg.day^{-1} in winter. Most households stated that they preferred using firewood because it is affordable (inexpensive) and readily accessible. The households also said that using firewood gives them options to do more than one household activity at the same time, such as cooking, boiling water and heating their houses.

The households in the township of Matlwang use indoor, hand-built stoves with attached chimneys to provide for both cooking and heating purposes. However, some houses in the township are poorly ventilated. As a consequence, when stoves burn there is a danger of smoke inhalation. The households also use “mbaula”/“imbawula” (brazier) stoves for cooking and heating. The households reported an mbaula is inexpensive to use and it is economical on firewood as it does not require a lot of firewood when cooking. They also stated that an mbaula neither produces nor spreads too many smoke emissions in the house as flames are channelled in one direction when it burns. Marufu *et al*. (1997) reported that an mbaula can save up to 60 % of firewood compared with a traditional three-stone fire. An mbaula is easy to move if the weather changes and it does not shed ashes when moved.

Many households (28 %) in the township reported that their homes are not electrified. As a result, they do not have access to electricity. The findings of the survey indicated that the lack and cost of electricity (particularly during winter) forced about 86% of the villagers to rely on a mix of energy sources. Households without electricity used cow dung, paraffin and gas to replace firewood and electricity during winter and occasionally in summer. The use of multiple energy sources for multiple purposes (“stacking”) is not a short transition phase but can last for decades, as shown in South Africa, Mexico and China (Masera *et al*., 2015). Since most rural regions in South Africa cannot afford electricity, they lack a reliable power source. Heating and cooking are the two main activities that require energy consumption. Activities like cleaning, sanitation, communication and entertainment account for a small proportion of the total energy demand of township households.

The smoke generated by solid fuels (burning wood) for domestic heating can have significant impacts on both indoor and outdoor air quality, with concomitant associated health and environmental concerns. In conclusion, the findings indicate that the households utilise approximately 20 (± 2.8) kg wood.household^{-1}.day^{-1} (summer) and 35 (± 7.1) kg wood.household^{-1}.day^{-1} (winter) or 4.8 (± 2.4)kg wood.person^{-1}.day^{-1} (summer) and 7.8 (± 2.9) kg wood.person^{-1}.day^{-1} (winter). The resulting CO_2, CO, NO and CH_4 emissions for the township are respectively: 894 (± 328), 85 (± 31), 1 (± 0.3) and 3 (± 1) Mt.annum^{-1}. Finally, the per caput CO_2 emissions reported for the township were found to be substantially less than the national per caput CO_2 emissions for South Africa.

KEYWORDS

Matlwang
Township
Households
Residents
Quantifying
Energy
Biomass
Solid fuels
Firewood
Firewood
Wood
Burning
Cooking
Heating
Emissions
Rural areas
Tree species
Poverty

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ABBREVIATIONS AND ACRONYMS

AIDS	Acquired immune deficiency syndrome
CO_2	Carbon dioxide
CO	Carbon monoxide
COPD	Chronic Obstructive Pulmonary Disease
CH_4	Methane
DME	Department of Minerals and Energy
DALY(s)	Disability Adjusted Life Year(s)
DC	Direct current (power)
DoE	Department of Education
EF	Emission Factor
ESMAP	Energy Sector Management Assistance Programme
FAO	Food & Agriculture Organisation
FBE	Free Basic Electricity
g C	Gram(s) of Carbon
GDP	Gross domestic product
GIZ	Gesellschaft für Internationale Zusammenarbeit [German Chamber of International Commerce]
HAP	Household air pollution
HIV	Human Immuno Virus
hr	Hour
HSRC	Human Sciences Research Council
IAP	Indoor Air Pollution
IAQ	Indoor Air Quality
ICS	Improved Cooking Stove

IFAD	International Fund for Agricultural Development
ICF	International Classification of Functioning
“Mbaula”/“Imbawula”	isiZulu names for a brazier
kg	kilogram(s)
km	kilometer(s)
LPG	Liquid petroleum gas
LPGSASA	Liquified Petroleum Gas Association of Southern Africa
N_2O	Nitrous oxide
NHAPS	National Human Activity Pattern Survey
NMHC	Non-methane Hydrocarbon
NO	Nitric oxide / nitrogen monoxide
NO_x	Nitrogen oxide
NPC	National Population Commission (of Nigeria)
NSS	National Sample Survey
NWU	North West University
O_3	Ozone
PAC	Polycyclic Aromatic Compounds
PAHS	Polycyclic Aromatic Hydrocarbons
PET	Poly Ethylene Terephthalate
PM	Parameter
QoL	Quality of Life (Survey)
SABS	South African Bureau of Standards
SAFE	Safe Access to Firewood and Alternative Energy
SSA	Sub-Saharan Africa
TCS	Traditional Cooking Stove

TJ	Terra joule(s)
Tg C = Mt C	Terra gram(s) carbon / Mega tonne(s) carbon
Tg $C.yr^{-1}$ = Mt $C.yr^{-1}$	Terra gram(s) carbon per year / Mega tonne(s) carbon per year
μm	Micrometre(s) (micron(s))
VOC	Volatile Organic Hydrocarbon(s)
WFP	World Food Programme
WHO	World Health Organisation

CHAPTER 1:
INTRODUCTION

This chapter gives a brief introduction and motivation for this study by providing a background of the state of domestic burning at a national and global scale. The research questions and objectives of the study are also outlined in this chapter.

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1.1 Background

The making of fire by burning woods is one of humanity's important advances. It is believed that wood usage as a fuel source is much older than civilisation and is assumed to have been used by Neanderthals (Leach & Mearns, 1988; Barnes, 2005). Nowadays, scorching of wood is the major source of energy derived from a solid fuel biomass. About 75 % of all energy in rural areas is generated through burning of wood (Marufu *et al*., 1997). Wood may be used indoors in a furnace, stove, or fireplace, or outdoors in a furnace. Globally, a significant number of people use firewood for cooking and heating, be it by using traditional stoves or open fires. Most of these stoves are fired with biomass fuels (such as wood, branches or twigs). When stoves are not available, agricultural residues or even leaves and grass are used. In most developing countries, the demand for firewood lead to destruction of forests and vegetation around urban and semi-urban agglomerations, resulting from unsustainable management practices and inefficient conversion and combustion technologies. This result in loss of biodiversity, soil erosion and a decline in water and air quality. It is estimated that "as many as 70 % of households in developing countries use fuels such as wood, dung and crop residues for cooking and heating" (Marufu *et al*., 1997).

The provision of firewood remains one of the most important contributions of forest and woody bushveld. (Food and Agriculture Organization (FAO), 2017). For example, cooking is one of the ways to ensure high nutrient absorption from food (Mustard *et al*., 2004; De Fries, Foley & Asner, 2004). Firewood is equally important for boiling and sterilising water, and is often the only available means that firewood-dependent communities have to ensure safe water for drinking and food processing. Firewood is also used in food preservation (for example: smoking, drying), which extends the supply of food into non-productive periods. About 795 million people are undernourished globally (FAO, IFAD and WFP, 2015) and the limited availability and access to firewood could exacerbate hunger and poverty by challenging the primary energy source for various purposes including cooking and sterilising water. FAO, IFAD and WFP (2015) further highlights that “firewood dependence varies largely among regions of the world and between urban and rural areas, reflecting different levels of development and the availability of alternative energy sources”. In most regions, firewood dependence has declined or remained steady over time. The exception is sub-Saharan Africa, where “per caput consumption is two to three times higher than in any other region of the world and total consumption continues to increase” (FAO, 2017).

The World Health Organisation (WHO) (2000), has a programme that aims to convert households from these fuels to modern fuels or from traditional stoves to more efficient and cleaner-burning stoves through reform of the energy sector or indigenous innovative technology. These interventions have been effective in some countries but dismal or non-existent in others. A wide variety of fuels (solid or liquid) is used in households in developing countries for cooking and heating. “Solid fuels” refer to both “biomass fuels” and “coal”. The most common fuel used for cooking and heating “is wood, followed by other solid biomass fuels, such as charcoal, dung, agricultural crop residues and, sometimes, even leaves and grass” (Wang, Yang & Zhang, 2012:2476). These fuels are often derived from the local environment in rural areas and are purchased through markets in urban areas.

Heltberg (2004) states that the majority of people who still cook using solid fuels (such as wood, crop waste, charcoal, coal, dung and kerosene) are poor and live in low- and middle-income countries. These cooking practices are inefficient because they “produce high levels of household air pollution with a range of health-damaging pollutants, including small soot particles that penetrate deep into the lungs” WHO (2016b). In poorly ventilated dwellings, indoor smoke can be “100 times higher than acceptable levels for fine particles”. Further, “exposure is particularly high among women and young children, who spend the most time near the domestic hearth” (WHO, 2016b). Although poor people have little alternative for energy services, they rely on biomass resources because they are trapped in a cycle of poverty. Poor households are limited in their ability to utilise energy for anything more than satisfying basic needs because other activities require many other energy inputs (such as electricity, shaft power and the heating process) that are simply not available through simple combustion of fuels (Marufu *et al*., 1997).

Poorer families tend to spend a huge chunk of their income on energy compared to middle to higher income households.

The simplest and most common method of cooking in rural areas of the developing world is the "three-stone fire, which typically transfers only 5 to 15 % of the fuel's energy into the cooking pot" (Kgathi, 1997). "Access to energy is important as it leads to eradication of poverty through improved education, health services and may eliminate structural unemployment" (Department of Energy, 2013). Solid fuels have been used by humanity for many years to create fire. Coal was the fuel source that enabled the industrial revolution, from firing furnaces to running steam engines. Both peat and coal are still used [in 2020] in electricity generation (Barnes, 2005). In some areas, smokeless coal is often the only solid fuel used. In Ireland, peat briquettes are used for home heating. They are also used to start a coal fire. Wood was also used extensively to run steam locomotives (Barnes, 2005).

Globally the use of firewood is common among rural dwellers. "The use of traditional biomass fuels such as firewood, dung, and crop residues is widespread in rural **India**. According to the 55^{th} round of the National Sample Survey conducted in 1999–2000" (NSS, 2000) covering 120,000 households, "86 % of rural households and 24 % of urban households rely on biomass as their primary cooking fuel in India". In many parts of Africa, most households continue to depend on firewood as a major source of energy. In **Nigeria**, for example, the proportion of households that relies on solid fuels for domestic needs is estimated to be 70 %, most of which (86 %) are rural households and the other 14 % are urban households. In **Tanzania**, Ifegbesan, Rampedi and Annegarn (2016) reported that 81.8 % of respondents in their study relied on firewood. In South Africa, the government has made huge strides to provide electricity to rural dwellers, but the use of solid fuels remains prevalent. An example is the **Giyani** area, in Limpopo Province, where 80 % of rural households rely on wood as their primary energy source for cooking and heating (Cooke & Shope, 2005). However, harvesting of wood has led to destruction and a general decrease of existing woody vegetation. Harvesting of firewood is physically demanding and time-consuming, especially for women and girls who are also responsible for other household duties. Harvesting wood causes environmental problems such as global warming, soil erosion and land degradation (FAO, 2015). The use of firewood leads to loss of trees as people tend to chop down trees, including indigenous and endemic species. Most indigenous trees take long to regenerate and felling them interrupts their natural cycle of regeneration. It has been noted that firewood harvesting is a major cause of the massive destruction of indigenous trees in many parts of Nigeria (Ayuba & Dami, 2011).

It is also vital to note that environmental challenges pertinent to firewood usage in rural homes projects “trees are harvested without replanting, which results in a net addition of heat-trapping carbon to the atmosphere” (Hassan, Mbuli & Dlamini, 2002:6). In the 1990s, increasing emphasis has been placed on promoting plantations of fast-growing multi-purpose species that produce firewood, timber, fodder, and other by-products to improve the micro-environment and mitigate this problem. The emphasis on multi-purpose tree species focuses on exotic species rather than indigenous species but, nevertheless, people continue to use indigenous species as long as they are available, thus placing them under severe threat of extinction. Perceptions and beliefs also impact on wood utilisation as opposed to other sources of energy. For example, there is a belief among Venda, Tswana and Shangaan people that porridge cooked using firewood tastes better than porridge cooked on an electrical stove. This perception also contributes to an increase in wood demand as an energy source in rural areas, resulting in the over-utilisation and ultimate degradation of the surrounding woodland resources (Prior & Cutler, 1992).

In Swaziland, trees such as *Colophospermum mopane* [mopane/mopani] are used for firewood as they produce quality fire due to their high density (Hassan *et al*., 2002). Among the most-harvested tree species in the Limpopo Province and the Bushveld Biome according to Uhunamure (2015) are *Dichrostachys cineria* and *Combretum inbrebe* which dominate the flat plains, the *Barchemia zeyheriis* species, mostly available in hilly areas and the *Selerocarya birrea* that is found mostly along rivers. The use of firewood for cooking and heating may also cause air pollution and harm to human health. According to Prior and Cutler (1992) the majority of people harvest trees randomly not knowing that there are trees whose smoke can have negative implications on their health. Incomplete combustion leads to the “release of small particles and other constituents that have been shown to be damaging to human health in the household environment. According to Smith (2000) there is no much data available on the health implications of smoke emanating from different tree species.

The local shortages of firewood place unacceptable burdens of drudgery on women and girls who are obliged to spend many hours collecting wood for domestic use. As the pressure on wood availability develops, the distance travelled and time taken to collect wood also increases (Hassan *et al*., 2002). For instance, previous studies reveal that in some villages in India during the early 1990s, women used to spend one to two hours per trip collecting firewood, which increased to three to five hours after forest protection policies were put in place (Agarwal, 2001). Some rather old data from Ghana and Zambia revealed patterns of burden on women of collecting firewood. Households in Ghana made at least one trip in two days to collect firewood, and in Zambia at least one trip per week. The time taken was 43 minutes and 92 minutes, respectively to collect 20 kg of firewood. The effort per household to collect firewood was 20 tonne-km in Ghana per year and 36.2 tonne-km per year in Zambia. Another study found that women in Mametja, Limpopo Province, spent an average of 4 hours per day harvesting firewood. As the distance travelled to collect the wood increased so did the incidence of crimes, such as rape and murder, perpetrated against women and girls. These hardships resulted in increased failure rates at school (Amacher, Koskela & Ollikainen, 2001). The effort required to collect firewood varies considerably from place to place, depending upon its availability, with typical rural women dedicating from 63 to 696 hours per annum (World Bank, 1994).

1.2 Problem Statement

In Africa, fifty-eight percent (58 %) of the energy supply comes from firewood and charcoal (Specht *et al*., 2015). Firewood is regarded as a renewable energy only if used sustainably whereby new trees are planted to replace the ones that are used. Firewood forms part of the energy mix in most rural households but, in time, the rural poor will run out of firewood due to trees being harvested in an unsustainable manner.

The use of firewood also contributes to the emissions of greenhouse gases as dry wood contains carbon, which is released when burnt or decayed, thereby increasing the contribution of emissions from domestic biomass burning to the global atmospheric trace budgets. The excessive and continual harvesting of firewood has greatly contributed to deforestation, as many mature trees are cut down in the process of obtaining firewood (Uhunamure, 2015). This poses a threat to the surrounding environment as it does not allow for appropriate planning and management of the biomass resources which sustain the majority of rural dwellers.

In addition, WHO estimates that "approximately 4.3 million deaths can be caused annually by household air pollution, with approximately 3.5 million deaths occurring directly as a result of household air pollution and 0.5 million deaths occurring as a result of exposure to outdoor air pollution associated with solid fuel combustion" (WHO, 2016). Pollution emitted as a result of domestic burning activities is estimated to be one of the leading causes of respiratory illnesses, prevalent in inhabitants of low-income settlements.

Low-income settlements in South Africa account for a large portion of South Africa's informal population. Usually residing in one of the many forms of informal dwellings, inhabitants of these households do not always have access to basic services such as electricity and therefore, seek alternative sources of fuels to meet their energy-producing needs" (Naidoo, 2014). Although a large number of both formal and informal settlements in South Africa have had access to electricity, research has shown that some people living in these electrified households continue to use fuels such as coal, wood, liquid petroleum gas (LPG), paraffin and other substances for domestic burning (Naidoo, 2014).

Matlwang is a small rural village west of Potchefstroom, North West Province in South Africa. Being a rural township, the residents of Matlwang (like many other rural dwellers in South Africa), rely on firewood for their day-to-day cooking and heating (Stats SA, 2018). The current study seeks a better understanding of the sources of domestic fuel, the quantities the villagers use and the resultant pollutants emitted from the burning of the fuel in the village. Information on firewood consumption is necessary to enhance understanding the sources of the atmospheric trace gases and to construct a credible assessment of its consumption.

It is also important to investigate the environmental problems associated with the extraction and use of firewood as a source of energy because of the assertion that many communities that rely on firewood live far from a stable electricity supply. Provisions of alternative and modern energy will ensure better, healthier and cleaner energy services as well as help save the remaining woodlands.

1.3 Research Questions

The specific questions of this study are:

- How important is wood as a solid fuel in Matlwang?
- Where do households of Matlwang source the firewood that they use?
- What are the preferred tree species for firewood in Matlwang?
- What is the current consumption rate of firewood in Matlwang?
- What are emissions that result from the combustion of firewood in Matlwang?

1.4 Objectives

The specific objectives of this study are to:

- Establish the prevalence of solid fuel combustion
- Identify the source of the domestic fuel

- Quantify the mass of firewood burnt in Matlwang
- Calculate the total emissions from the firewood burnt in Matlwang

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A brief description and rationale for the project was provided in this chapter. The research questions and objectives of this study have been clearly defined in this chapter.

CHAPTER 2:
LITERATURE REVIEW

This chapter discusses the importance of firewood as a resource for many rural communities, the sources of firewood, preferred species being harvested and the environmental implications at the current rate of extraction. The chapter also covers a detailed description of all fuels burnt and their associated pollutants and greenhouse gases that are emitted from the combustion processes. This chapter also discusses the climatic effects and the health risks associated with the resulting emissions.

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2.1 Introduction

Energy is an indispensable need for human lives. Its availability is the pre-requisite for many activities in business and at home. The demand for energy remains high due to growth in the economy and upgrade in the standard of living. Due to urbanisation and changing lifestyles, consumption of energy by households has changed substantially resulting in significant increases in energy use (Naidoo, 2014). A household's choice of source of energy is driven by a number of factors. Such factors include access to electricity, income level (household wealth), the age of the dwellers, gender and education of the household heads, occupation of the household head and spouse, household size, per-capita expenditure. Among other factors influencing the energy choice are: the types of food usually cooked, the type of cooking pots commonly used, the ownership of the main dwelling unit, and the materials with which the main dwelling unit was constructed, its position, climate, forest cover and altitude all influence energy sources that are used (Naidoo, 2014). According to Kiyawa and Yakubu (2017), the determining factors of energy choice are divided into two sub-sections: endogenic and exogenic factors.

The ***endogenic*** factors are those pertaining to household characteristics. These factors are sub-divided into three sub-categories, namely:

- Economic characteristics (such as household income and household expenditure);
- Non-economic characteristics (such as household education, age, size and composition), and

- Behavioural and cultural characteristics (such as taste of food cooked with a particular type of energy).

In contrast, ***exogenic*** factors are those that lie outside the household domain and are considered external conditions that have an effect on fuel choice. They are also sub-divided into three sub-categories, namely:

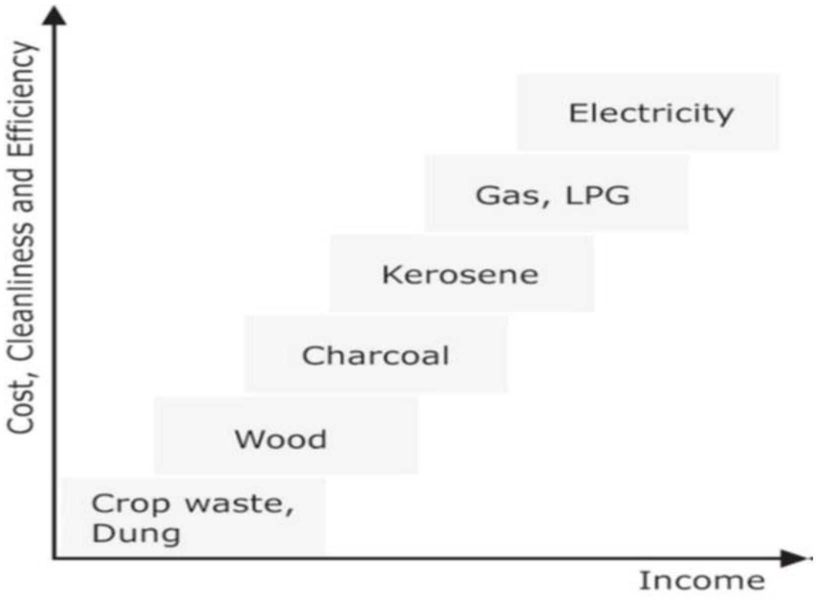
- Physical environment such as location of a country, urbanisation and climate (Kiyawa & Yakubu, 2017).
- Energy policies and regulations (for example, government intervention in the form of subsidising the cost of LPG fuel cylinders and petroleum taxed products).
- Energy supply factors which relate to availability, affordability, accessibility and reliability of fuels.

The concept of household energy choice can also be explained by either the "energy ladder" or "fuel stacking" (Heltberg, 2004). The ***energy ladder*** model explains the transition in energy consumption from traditional animal/plant residue to modern sources is caused by an improvement in income. This model is based on a three-stage fuel-switching process:

- In the ***first stage***, households rely on animal/plant residue and wood.
- In the ***second stage***, with improvement in income, households move to transition fuels such as kerosene and charcoal.
- In the ***third stage***, with a further improvement in income, households adopt modern sources of energy.
- In the ***fuel-stacking*** model, households do not completely discard traditional sources of energy as their income rises. Instead, they simultaneously use both traditional and modern energy sources.

Heltberg (2004) stated that energy use depends upon the accessibility/availability as well as the cost of that type of energy. Seeing the poverty of developing countries and the price increases for petroleum products, firewood is still the fuel most used in rural areas, whereas charcoal is mainly intended for large cities. For example, 90 % of the population in Abidjan use charcoal in their households (Zidago & Wang, 2016).

Figure 2.1 shows the influence of household wealth on choice of energy source.



Source: (Duflo *et al*., 2008).

Figure 2.1: Graph showing the influence of income in energy choice

It is believed that the use of biomass fuels worsen the health issues and quality of life for the poor. "The increased quality and convenience of fuels are usually accompanied by a higher energy cost, leading to a trade-off between fuel quality and cost" (Masera *et al*., 2015). A gradient of "fuel quality, convenience and cost" rises from solid fuels such as firewood and charcoal at the bottom to liquid fuels such as gas, oil and, finally, electricity at the top. Consequently, poor households resort to the use of firewood, dung and crop waste, while higher income households with good financial standing, use electricity. However, Lin *et al*. (2014) noted that "the cost of using firewood is determined by the opportunity cost of household members' labour time used to gather firewood from forests or woodlots". Nowadays, it is recognised that households use different fuels for different purposes and that firewood is likely to be part of this energy mix at the global level. The use of multiple energy sources for multiple purposes (known as "stacking") is not a short transition phase but can last for decades, as Masera *et al*. (2015) noted occurs in **Mexico** and **China**.

Different energy mixes are used by households – ranging from ***modern*** energy commodities (for example, electricity, natural gas) to ***traditional*** biomass energy commodities. In **developing countries**, households generally use a mixture of energy sources for cooking that can be further categorised as ***traditional*** (such as dung, agricultural residues and firewood), ***intermediate*** (such as kerosene and charcoal), and ***modern*** (such as LPG, electricity, biogas, natural gas). In **developing countries**, electricity is used mainly for lighting, appliances, entertainment and represents a small share of total household energy consumption. In contrast, households in developed countries used modern energy sources as an energy mix. **Pakistanis** consume energy from both modern and traditional sources for different purposes (such as lighting, cooking, heating and transportation). ***Modern*** sources of energy include electricity, oil, gas and coal, while ***traditional*** sources consist of animal/plant residue (firewood, crop residue and animal waste (Onoja, 2012).

In **South Africa**, rural households tend to use a mix of energy sources, with electricity used mainly for lighting (Madubansi & Shackleton, 2006), this despite the fact that electricity is subsidised in most of these areas (Davis & Steyn, 1998; Thorn *et al*., 2012). Rural areas in South Africa, like in many other developing countries, "are less privileged in terms of social services and infrastructure" (Masekoameng *et al*., 2005). As most rural areas in South Africa cannot afford a reliable power source, electricity is not a realistic fuel option for rural households. Heating and cooking are the two main household consumers of energy (Masekoameng *et al*., 2005). The remaining uses (like cleaning, sanitation, communication and entertainment) account for a minor proportion of energy used. In many areas, when winter arrives or even just as the sun goes down, lighting a fire to stay warm is a matter not only of comfort but of survival. Heating is an essential energy service for people of all ages, but it is especially important for the health of infants, children, the elderly and those who are ill. Even though heating is such a fundamental need for so many, space heating is a largely overlooked source of household air pollution (HAP) and health risk. In **China**, "heating and cooling are the main users of energy in households; almost 68 % of household energy is used for heating and cooling" (Onoja, 2012).

The scarcity of energy can increase the risk of malnutrition. As cooking fuel becomes scarce, households may resort to negative coping mechanisms such as switching to less nutritious foods with shorter cooking times, undercooking food or reducing the number and size of meals. The World Food Programme (WFP) has reported that selling or bartering food for fuel is a commonly adopted strategy especially in contexts where food is the main, if not the only, source of income. These practices negatively affect "the quantity, quality and nutritional value of the food consumed" (WFP, 2012) and pose particularly grave risks for pregnant and breastfeeding women and their children. Household and commercial cooking directly contributes to the utilisation dimension of food security, making food more digestible. Cooking food enhances the uptake of nutrients. Many foods with high nutritional value (such as beans and cereals, which are especially important in the diets of people who cannot afford animal protein), require long cooking times.

In addition, cooking increases the bioavailability of certain micronutrients in food such as beta-carotene (in foods such as tomatoes, carrots and sweet potatoes) and lycopene (an anti-oxidant found in tomatoes) and allows iron and other minerals to be better absorbed by the body. Cooking and reheating food also increase food safety by eliminating dangerous micro-organisms and removing toxic elements. Untreated drinking water may contain parasites and pathogens that cause diarrhoea, typhoid or dysentery. An estimated 663 million people globally in 2015 had no access to clean, safe drinking water and had to source water from unprotected wells, springs and surface water (United Nations Children's Fund (UNICEF) & World Health Organization (WHO), 2015). Boiling is the most common method for treating drinking water, used by around 20 % of people in developing countries (UNICEF and WHO, 2011). "An estimated 1.38 billion people in Africa, Asia, Latin America, the Caribbean and Oceania treat drinking water by boiling it and about 765 million people (10.9 % of the global population)" use firewood to generate the energy for this purpose (Food and Agriculture Organisation (FAO), 2014). Clean water is also needed to wash food for general household hygiene and for treating wounds (WHO, 2006a).

Since 2010, it has become increasingly apparent that the trace gas composition of the atmosphere is changing, and its environmental consequences are noticeable (He, Joshi & Zhang, 2013). One of the causes of this change has been linked to biomass burning, especially since it occurs over extensive areas and appears to be increasing every year (He *et al.*, 2013).. ***"Biomass burning"*** refers to "anthropogenic activities associated with savanna burning, slash-and-burn for agriculture, burning for deforestation purposes and for disposal of agricultural waste, biofuel burning as well as forest wildfires". In contrast, ***"biofuel burning"*** refers to "all burning for purposes of domestic energy generation only" (Marufu *et al*., 2000). Most biofuel burning occurs in the **developing world**, where the background 50 % to 60 % of the energy in developing countries of Asia, and 70 % to 90 % in Africa comes from wood or biomass (FAO, 2014). Half the world's population uses wood to cook. Depending on the wood availability in different countries, households either let the firewood burn down on its own or quench it with water soon after it has been used. This has implications for trace gas emissions in that the longer the duration of the fire, the more trace gases are produced. Countries with plenty of biofuel (such as Zimbabwe, South Africa, Asia and Zambia) usually burn fires for longer and emit more trace gases than countries with limited biofuel resources.

Trace gases (carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_x), non-methane hydrocarbons (NMHCs)) and aerosols released through biomass burning have a significant influence on climate and biogeochemical cycles (Crutzen & Andreae, 1990). Biomass burning contributes to the greenhouse effect directly through the emission of methane (CH_4) and nitrous oxide (N_2O) and indirectly through the production of tropospheric ozone (O_3) (Lindesay, 1992).

Asia contributes the most to the biofuel-burning emissions budget of the **developing world**, mainly due to **China** and **India** accounting for 71 % of the Asian total. **Africa** is the second largest contributor (Table 2.1) (Yevich & Logan, 2003). Table 2.1 shows the emission estimates from domestic biomass combustion for three regions across the developing world.

Table 2.1: Emission estimates from domestic biomass combustion for 1995 for three regions across the developing world

Region	Emission estimate			
	CO_2 ($Mt\ C.yr^{-1}$)	**CO** ($Mt\ C.yr^{-1}$)	**NO** ($Mt\ N.yr^{-1}$)	**CH_4** ($Mt\ C.yr^{-1}$)
Asia	1808	102	1.41	5.93
Africa	527	28	0.40	1.66
Latin America	353	20	0.20	1.16

Source: Yevich and Logan (2003:27).

2.2 Types of Fuel Utilised in Rural and Urban Areas

2.2.1 Firewood

"Firewood" is defined by the Food and Agriculture Organization (FAO) of the United Nations as wood in the rough from trunks and branches of trees to be utilised as energy for purposes such as cooking, heating or power production (FAO, 2014). Wood consists primarily of two polymers, namely, cellulose (50 % to 70 % by mass) and lignin (approximately 30 % by mass). In wood, cellulose compounds form a supporting mesh that is reinforced by lignin polymers. Together these compounds form the rigid wood structure. Upon heating, these structures break apart producing a large variety of smaller molecules including methoxy phenols, methoxy benzenes, phenols, catechols, benzene, and alkyl benzenes. Non-wood biomass does not contain lignin and therefore the methoxy phenols and methoxy benzenes are unique tracers of wood smoke combustion. Conifers (softwoods) produce large amounts of resin acids, while deciduous (hardwoods) trees do not. Combustion of hardwoods produces more ash and therefore more trace elements than softwoods. Approximately 5 % to 20 % of wood smoke particulate mass is elemental carbon, while the composition of the organic carbon fraction varies with the specific biomass fuel being burned and with the combustion conditions. Potassium is the trace element found at highest concentrations in wood smoke and has often been used as a wood smoke tracer.

Firewood remains “a primary energy resource among electrified South African households in rural communities” (Uhunamure *et al*., 2017). According to Makonese *et al*. (2018), “firewood is the preferred energy resource for cooking and heating in most southern African countries (such as Angola, Lesotho, Malawi, Namibia, Swaziland, Zambia and Zimbabwe)”. Moreover, firewood is equally important for boiling and sterilising water, and is often the only available means that forest-dependent communities have to ensure safe water for drinking and food processing. Firewood is also used in food preservation (for example, smoking, drying), which extends the supply of food into non-productive periods. Firewood is an essential energy source for more than 85 % of southern Africa’s rural inhabitants (MacGarry, 1987). Of villagers in woodland-depleted villages, 84 % and, in woodland-abundant villages, 76 % use firewood as their main source of energy for cooking and heating. Areas of Imo State (in Nigeria) depend mainly on firewood for domestic cooking as well as small-scale processing such as *garri* / *gari* (the cooked flour cakes made from dried cassava flakes) and palm-oil processing.

Firewood is currently, and likely to remain, the primary source of energy in rural areas for the foreseeable future. Good forestry practices and improvements in devices that use **firewood** can improve the local wood supplies. Firewood can be either seasoned or unseasoned and can be categorised into hardwood and softwood. In comparison with hardwoods, softwoods burn more quickly and generate less heat due to the lower energy content per unit volume. However, the energy content per mass of wood is similar for all hard and softwoods. The moisture content of firewood primarily determines its energy content. “The drier the biomass, the less energy required to evaporate the water inside the wood and, thus, the more energy available for heating or cooking purposes. In most of the United States, the standard measure of firewood is a “cord”[1]. However, firewood can also be sold by mass” (Campbell *et al*., 2002).

[1] A “cord” of dry wood is the amount of wood that, when “racked and well stowed” (arranged so pieces are aligned, parallel, touching and compact), occupies a volume of 128 cubic feet (3.62 m^3). This corresponds to a well-stacked woodpile 4 feet (1220 mm) high, 8 feet (2440 mm) wide, and 4 feet (1220 mm) deep; or any other arrangement of linear measurements that yields the same volume [Source: *Wikipedia*, sv: “cord of wood”].

Most people in rural and urban areas of northern South Africa, southern Zimbabwe and eastern Botswana preferred to buy firewood of the *Colophospermum mopane* species (Makhado *et al*., 2009). It is one of the most important tree species in southern Africa. This tree species is used for firewood and poles to construct traditional structures (Liengme, 1981; 1983). *Colophospermum mopane* is also used for treatment of various animal and human diseases in southern Africa (Watt & Breyer-Brandwijk, 1962), and hosts mopane worms which are the larvae of the moth *Imbrasia belina*. Mopane worms are consumed widely in southern Africa for household nutrition (Mpuchane *et al*., 2001) and are sold to generate incomes (Styles, 1994; Kozanayi & Frost, 2002). Other viable products harvested from mopane woodland by rural dwellers include stinkbugs, termites, edible locusts, edible mushrooms, honey, thatching grasses and wild fruits (Makhado *et al*., 2009). *Colophospermum mopane* dominates the hot, low-lying areas of south tropical Africa (Werger & Coetzee, 1978). The area covered under mopane woodland in southern Africa is estimated to be about 555,000 km^2. The Limpopo and Mpumalanga Provinces of South Africa have about 23,000 km^2 of mopane woodland (Mapaure, 1994). Mopane woodland is distributed along the Limpopo River in South Africa (Mapaure, 1994), contributing to about 50 % of the vegetation in the Kruger National Park. The controls on the growth and distribution of *Colophospermum mopane* in southern Africa are uncertain, but seem to be influenced by edaphic and climatic factors (Timberlake, 1995). *Colophospermum mopane* is a drought-tolerant species confined to areas of low to moderate rainfall, dominated by alluvium and colluvium soils (Timberlake, 1995). Mapaure (1994) is of the opinion that "its distribution is principally influenced by moisture availability expressed through altitude, rainfall and soil texture".

In southern Africa, the **mopane woodland** lies "in areas between altitudes of 300 m and 1,000 m above sea level, typified by a mean maximum summer temperature of about 30 ^{o}C and a mean annual rainfall of between 400 and 700 mm" (Werger & Coetzee, 1978; Timberlake, 1995). *Colophospermum mopane* occurs generally in frost-free areas. Where frost does occur, it becomes the limiting factor to its growth (Werger & Coetzee, 1978; White, 1983). Despite the value of mopane woodland, its resource is over-utilised, mis-managed and even transformed to other land use. This has resulted in the circles of degradation surrounding the villages. The main drivers of woodland resource depletion around the villages are the result of high population pressure, coupled with poverty (Watson & Dlamini, 2003), lack of woodland management responsibilities and diminished power of traditional leaders (Evans, Shackleton & von Maltitz, 2000; von Maltitz & Shackleton, 2004).

Firewood is regarded as a renewable resource. However, demand for this fuel can outpace its ability to regenerate it on a local and international level. For example, in some places in the world and through history, the demand has led to desertification. Examples of such places are **Ghana** and **Ecuador**. According to Masera *et al*. (2015), "high urban demand for firewood creates pressure on peri-urban forest and tree resources, contributing to land degradation, which can have a negative impact on food availability as these lands are also needed for agricultural production to feed urban populations". Between 2010 and 2015 an annual loss of forest cover of about 7.6 million hectares, partially offset by an annual gain of about 4.3 million hectares, resulted in a net annual decrease in forest area of about 3.3 million hectares worldwide (FAO, 2015).

Limpopo Province, "with a large proportion of its population living in rural areas, has the highest consumption of firewood in South Africa, with 40 % in 2014 relying on firewood for cooking, leading to problems of deforestation and soil erosion" (Statistics South Africa, 2015). Harvesting or collecting firewood varies by region and culture. Some places have specific areas for firewood collection, mainly on hillsides and in valleys. Other places may integrate the collection of firewood in the cycle of preparing a plot of land to grow food as part of a field-rotation process. Collection can also be done in a group, family or as an individual activity. What is more, it can be done for private or commercial use. In the past, firewood collection mainly involved collecting deadwood. However, due to rising populations and an increase in demand for firewood, most of the deadwood has been picked and the women resort to cutting down young trees. Therefore, women's unfair access to resources can lead to poverty and worsen deforestation and, consequently, deforestation worsens both poverty and women's access to resources.

In **Argentina**,"wood was used for railroads, the tanning industry, posts, fences and vineyards; all associated with the roaring boom of agriculture which became a model for the dominant economic development" (Williams & Shackleton, 2002). Within **South Africa**, most of the rural population makes extensive of firewood, despite increased electrification in the last decade. The annual demand is ~ 11 Mt (Department of Minerals and Energy (DME), 2001), well within sustainable supply at a national level (Williams & Shackleton, 2002). However, in many areas there is a "severe imbalance between demand and supply for firewood at a localised scale, resulting in progressive deforestation, and it is most apparent in areas of high human population density, although not ubiquitous to them all" (Banks *et al*., 1996).

The Energy Commission of Nigeria in its 2003 report estimated that more than 60 % of the **Nigerian** population depends on firewood for cooking and other domestic uses. However, in 2013 the percentage of Nigerian households that consumed firewood for cooking escalated to about 72 % as put forward by National Population Commission and ICF International (2014). This huge population and growing numbers of people in the country led to the conclusion that the nation's 15 million hectares of forest and woodland resources could be depleted within the next fifty years [by the 2060s] (Food and Agriculture Organisation (FAO), 2016). The scenario would degenerate not just to deforestation but also lead to environmental effects, health effects and conservation effects.

Globally, the production of **firewood** has also been increasing, although at a slower rate since 2010, from ~ 8,699,979 m^3 to ~ 9,034,617 m^3, almost a 4 % rise. **Firewood** is produced from tree fallow, shrub fallow, woodlots, tree-plantation sites, re-forestation sites, agro-forestry systems (fruit trees or scattered trees) and shrubland areas. Most firewood is not actively produced in developing countries but, rather, households collect it directly as a common property resource. Consequently, **Europe's** wood production increased from ~ 125 ,000,000 m^3 in 2001 to nearly 160,000,000 m^3 in 2011 (FAO, 2012). During harvesting of wood, local farmers gather firewood and bring it to the nearest roadside by head-loads, bicycle-loads or donkey carts. They can sell the firewood to local traders or to transporters. The latter serve as the principal carriers of firewood to urban areas. **Asia** is the region with the highest production of firewood, accounting for ~ 771,000,000 m^3 or nearly 45 % of global production. This role is strongly driven by **China** (Zhang, Lu, Wang & Qian, 2018) and **India**. These two countries account for > 25 % of global firewood consumption. However, **Asian** consumption of firewood has decreased by 3.2 % on account of substitution for other fuels (as noted by Zhang, Lu, Wang & Qian, 2018).

Firewood consumption in **Africa** and **Latin America** has continued to grow (FAO, 2013). According to the legal provisions in most countries, a cutting permit is required order to harvest a prescribed amount of wood from a designated area. In reality, however, wood harvesting, transport and trade are often unregulated. In places where legal restrictions actually do apply, they are frequently ignored due to a lack of legal-regulatory coherence and enforcement capacities in those countries. Although firewood use is associated with many negative impacts (Ezzati & Kammen, 2001); in contrast, the widespread availability and potential renewability of, and enormous market for, firewood creates employment and presents opportunities for sustainable value chains. Compared with charcoal, the production of firewood contributes less to deforestation and degradation for two reasons. ***Firstly***, the direct use of firewood requires smaller quantities of wood to satisfy the same energy needs as there are no conversion losses. ***Secondly***, firewood is less commercialised and a great portion of consumed firewood is covered by the collection of dead branches, trees outside of forests or fallow land. However, in many areas (especially around larger villages and cities), the amount of harvested firewood exceeds the annual growth rate of forest resources while inefficient harvesting and utilisation practices are prominent (Ezzati & Kammen, 2001).

The tools and methods for harvesting firewood are equally diverse with axes and machetes being the main tools used in Africa. **Firewood harvesting** is rated as the most serious environmental issue in developing countries. One of the strategies adopted initially to combat deforestation in early developing countries was to optimise biomass consumption at the household level by improving the technical performance of cook stoves, and encouraging families to move up the energy ladder by switching to alternate fuels (Creswell, 2009). Some firewood is harvested in woodlots managed for that purpose but, in heavily wooded areas, it is more usually harvested as a by-product of natural forest. **Deadfall** that has not started to rot is preferred, since it is already partly seasoned. Standing dead timber is considered better still, as it is both seasoned and has less rot. Harvesting this form of timber reduces the speed and intensity of bushfires. "Harvesting timber for firewood is normally carried out by hand with chainsaws. Thus, longer pieces – requiring less manual labour and less chainsaw fuel – are less expensive and limited by only the size of one's firebox" (Fernando, 1997). Historically, the main use of a donkey has been for transport. For many years, donkeys provided the only alternative to head-loading, back-packing and walking. This is a cheap and easy way of transporting goods, especially over rough and hilly terrain. "As long as the load is correctly placed on the back of the animal and a proper loading system is used", an average donkey of approximately 11 hands high or 160 kg can carry up to 50 kg (8 stone) on its back (Fernando, 1997). Most people in rural areas collect firewood using a donkey cart. Donkey carts are usually owned by men. They are increasingly playing a role in the camp and firewood markets.

Firewood in most rural areas is free of charge from the surrounding environment, thus areas with high firewood availability tend to have higher consumption rates. Large quantities of trace gases are emitted in areas where there is enough firewood for domestic energy generation. For example, **Mozambique** has abundant, woody and dense vegetation across the entire country, for cooking and lighting functions, as well as, simultaneously, for space-heating purposes. Prices of firewood vary considerably with the distance from woodlots, and quality of the wood (Erakhrumen, 2010). Buying and burning firewood that was cut only a short distance from its final destination prevents the accidental spread of invasive tree-killing insects and diseases.

Source: Own photograph taken during field survey (05 February to 16 February 2017)

Figure 2.2: Two donkeys pulling a cart laden with firewood

Karekezi (2002) estimated that a distance of 80 km from cut site to final burning site is considered the greatest distance that firewood should be moved. During winter, low-income households favour solid fuels (such as wood) because they are readily available. However, other substances (such as paraffin, coal, LPG, animal dung) and electricity are also utilised to provide for the energy needs of inhabitants of low-income settlements. As the temperature decreases, the rate at which these solid fuels are consumed increases. Streets and Waldhoff (1999) showed that areas that burn large quantities of **firewood** have a higher proportion of CO_2 and CO emissions.

2.2.2 Charcoal

(Hofstad *et al*., 2009) defined charcoal as a porous black solid consisting of an amorphous form of carbon obtained as a residue when wood, bone or other organic matter is heated in the absence of air. Charcoal is processed from firewood in the carbonisation process. This carbonisation process also produces trace gases. The carbonisation process is generally inefficient, and "it is estimated that it emits 60 % by mass of the original wood as CO_2, CO and CH_4 " (Kituyi *et al*., 2001a; 2001b). Charcoal is mostly pure carbon, called “char”, made by burning wood in a low-oxygen environment, a process that can take days and burns off volatile compounds such as water, methane, hydrogen, and tar. In commercial processing, “the burning takes place in large concrete or steel silos with little oxygen, and stops before it all turns to ash” (Hofstad, 2009). The process leaves black lumps and powder, ~ 25 % of the original mass.

In contrast, another estimate (Garland *et al*., 2015) suggests that six to twelve tonnes of wood are required to make one tonne of charcoal. Therefore, by using charcoal instead of firewood, one loses up to six times the total amount of energy contained in the original firewood. Charcoal is produced and either sold within a country or exported to neighbouring countries. Unlike wood, charcoal costs money. The price of charcoal varies with country and place. In areas that are closer to town, charcoal is more expensive than areas that are far from the town since charcoal is made in rural areas where there is a high density of vegetation. Charcoal is perceived to have its negative effects, though it is priced more competitively than LPG and kerosene which continue to be too expensive for many people. Furthermore, as in the case of firewood, charcoal can also be purchased in small quantities for very little money on a daily basis. Although the purchase price per kilogram of charcoal is often many times higher than that of firewood, this is not necessarily the case for the price per unit of useful energy. The production of charcoal and the unsustainable cutting of firewood contributes to “deforestation and forest degradation which is the third-largest contributor to climate change” (Garland *et al*., 2015). In areas with high population pressure, the extraction of wood for fuel purposes may accelerate deforestation and forest degradation which increases the risk of drought, soil erosion and landslides. Pollution derived from cooking on open fires is responsible for 25 % of black carbon emissions, thus further contributing to climate change. One great concern, however, is that charcoal, unlike firewood, is most often produced from forest resources. Thus, the use of forest biomass for charcoal making could still represent a threat to the future of the resources in local terms, especially in certain situations with high demand and lack of proper forest management practices and regulations. The shift from firewood to charcoal, even if it lasts only a few decades, could have major ecological consequences if it is not kept under control. However, since charcoal stoves are more efficient than wood stoves, the ratio of primary energy to usable energy is almost the same as with firewood.

Charcoal production has increased substantially, rising by 22 % from 400,850 tonnes in 2003 to 488,128 tonnes in 2012 in order to meet the demands of a growing, and increasingly urbanised, population (FAO, 2013). Global production of wood charcoal was estimated to be 47,000,000 tonnes in 2011. Since 2003, global production of charcoal has increased by 11 % (FAO, 2013). More than 80 % of this wood-based energy is used for domestic purposes: due to population growth, coupled with increasing urbanisation, charcoal demand is expected to continue to grow, especially in low-income countries. Furthermore, the charcoal business in developing countries is often left deliberately to the informal sector. This results in insufficient monitoring of production and consumption data and an ensuing lack of necessary baseline information for shaping charcoal policies. **Brazil** remains the largest charcoal-producing country in the world with 6,900,000 tonnes produced in 2011. **India** and **China** are the two most important charcoal producers in Asia, and have experienced stable charcoal production over the past 10 years (FAO, 2013). **Kenya** and **Ethiopia**, for example, have had tight restrictions on charcoal production for many years but these have had little impact on demand other than to drive up prices and encourage corruption. Bans have had similar effects in **Cameroon**, **Malawi** and the **United Republic of Tanzania** (Zulu, 2010; GIZ, 2015). Global wood charcoal production trebled between 1964 and 2014, increasing from 17,300,000 t to 53,100,000 tonnes. Of the current global production, 61 % occurs in Africa, primarily to satisfy cooking-fuel demand from urban and peri-urban households (Doggart & Meshack, 2017).

The employment status of a society is a critical measure of the economy and also relevant to energy use. Apart from its negative effects, the World Bank / Energy Sector Management Assistance Programme (ESMAP) estimates that charcoal creates between 200 to 350 jobs per TJ of consumed energy, whereas electricity creates only between 80 and 100 jobs, LPG 10 to 20 jobs and kerosene 10 jobs for the same amount of consumed energy, suggesting that the promotion of charcoal can create more jobs than any other fuel. In **Sub-Saharan Africa**, it is estimated that 13 million people are employed in the biomass energy sector; if the substitution of biomass by LPG is encouraged, people will have to find alternative employment. This likewise brings the risk of increased deforestation and greenhouse gases as people would be forced to clear more forests and woodlands for agriculture and pastoralism. Schwabe (2004) revealed that as family size increases, disposable household income decreases. **Firewood commercialisation** can contribute to household income diversification. Firewood trade can act as a safety net for households during periods of food shortage, by providing cash to purchase food as described by Koffi, Djoudi and Gautier (2017) in rural **Burkina Faso**. In **Ethiopia**, where many people are chronically food insecure, firewood and charcoal trade provide a coping strategy to generate income and purchase food in drought years (Endalew, Muche & Tadesse, 2015). In particular, charcoal generates revenue for women, who often dominate in its marketing and retailing (Ingram *et al*., 2014; Zulu & Richardson, 2013; Sunderland *et al*., 2014). However, charcoal production for commercialisation is mainly carried out by men (Ingram *et al*., 2014), and, in some cases, it has diverted labour away from agriculture, leaving women with more work (Zulu & Richardson, 2013). Most people in urban and rural areas prefer charcoal for cooking and space heating. Charcoal use is more common in middle-income households in urban areas than in poor rural areas, and is preferred to firewood because of its higher energy content, ease of storage and transportation and lower smoke emissions. Kituyi *et al.* (2001a; 2001b) suggested that household energy choice depends not only on income and available energy. Several studies in different countries have shown that all women who use wood or charcoal for cooking are exposed to serious dangers. "The amount of each pollutant released is dependent on combustion conditions (such as energy density, combustion temperature and air flow, and pollutant emission rates), which vary with time and stove geometry" (Ezzati & Kammen, 2001).

Charcoal grilling might not offer the same level of convenience as other solid fuels, but it does boast one benefit that stands out above all others: the smoky flavour it imparts to food (Yan, Ohara & Akimoto, 2006). The dry, white-hot heat of charcoal sears meat quickly, creating a crusty, caramelised exterior and smoky flavour. Since it is not possible to reduce the heat of white-hot coals, it is a good strategy to leave empty spaces on the lower grill grate. These cool spaces allow for better control, letting people sear food first over the hot spots before transferring it to cooler parts to complete cooking. Another advantage is that a bag of charcoal can easily be transported by car and taken to the park or beach (Andreae *et al*., 1996). Charcoal burns hotter, cleaner and more evenly than wood. Charcoal produces fewer noxious fumes when burnt. Consequently, cooking pots stay cleaner for a longer time in areas where wood is a freely accessible good; traditional charcoal makers have no incentive for improving production. Charcoal, derived from firewood, "is a renewable energy source that has the potential to power economic growth while reducing the dependency on costly energy imports in poor developing countries. An added advantage of using charcoal over firewood is that charcoal has a higher energy content per kilogram of fuel burned, is less bulky and easier to store and transport, and burns with fewer smoke emissions". In many developing countries, a complete transition to charcoal would reduce the incidence of acute respiratory infections by 65 %.

2.2.3 Electricity

Electricity is a form of energy resulting from the existence of charged particles (such as electrons or protons), either statically as an accumulation of charge or dynamically as a current. Regardless of the chosen fuel, most generators operate on the same proven principle by turning a turbine so that it spins magnets surrounded by copper wire in order to get the flow of electrons across atoms which, in turn, generates electricity. **Coal** and **gas** work in similar ways. They are both burned to heat water which creates steam and turns the turbine. Renewable energy sources – such as **hydropower** and **wind** – operate slightly differently with either the water or the wind being used to turn the turbine and generate the electricity. **Solar photovoltaic panels** take a different approach as they generate electrical power by converting solar radiation into electricity using semi-conductors (Scorgie *et al.*, 2003).

Most of the electricity supply in **Australia** has been generated from traditional fuels such as coal and natural gas with around 14 % coming from renewable energy sources (Balmer, 2007). In Bhutan, the rapid rise in modern renewable energy source such as electricity in Bhutan "is evident due to an increased availability of electricity from several hydropower projects installed with the financial and technical assistance of the government of **India**" (Balmer, 2007). "Ninety-seven percent (97 %) of the population in urban areas has access to electricity, while in rural areas only 56 % can access electricity" (Balmer, 2007). Developing countries have varyingly low levels of electrification. Within **Sub-Saharan Africa**, ~ 42 % of the population has access to electricity, compared with ~ 65 % in **South Asia** and > 90 % in **East Asia**.

In **South Africa**, electricity is accessed by 91.23 % of the population even though it is not the only source of energy used for cooking and heating particularly so for the poor mainly in the rural areas (Stats SA, 2018). The main reasons for low rural electrification levels are the low in-country generation capacities, coupled with weak, damaged or under-developed electricity transmission and distribution infrastructure (Muller *et al.*, 2003). With information from energy management group, the National Utility Service Consulting, electricity tariffs increased by 300 % from 2007 to 2015. Over the same period, inflation was 45 %, according to electricity use and billing management solutions company (PowerOptimal). It expects that the total increase in electricity tariffs from 2007 to 2017 for South Africa could be 495 %, compared with 74 % for inflation over the same period. While electricity is the most utilised source of energy for cooking in South African homes and guest houses, more and more rural poor are starting to switch to other solid fuels such as wood and dung. This is largely due to the changing energy landscape marked by electricity supply constraints and rising costs. Several studies showed that by replacing electrical energy stoves with gas stoves, the electrical energy consumption of stoves in a household can be reduced effectively. Relative to South Africa's annual Gross Domestic Product (GDP) per caput, which is USD 12,700, electricity prices were on average about ZAR 1 kW hr^{-1} in 2014.

In **Italy**, the country in Europe with the highest electricity price according to the same survey (about ZAR 2.56 in 2014), the GDP is USD 28,376. Thus, it is clear that – compared with Italy – the average South African household cannot afford the rising electricity prices and many households are now seriously considering and implementing alternative energy sources such as gas and firewood. A study by North-West University's (NWU's) Faculty of Engineering in Potchefstroom (North West Province) shows that a household can save up to 58 % of its electrical energy consumption, provided that the house has all of the most efficient appliances and systems. There are > 9,000,000 electric hotplates and stoves in use in South African households (DoE, 2013).

The **South African** government (via the State-Owned Enterprise, Eskom) is working towards ensuring that everyone has access to electricity in South Africa. Consequently, the price of electricity will rise rapidly in households connected to the national grid. Further, policy benefits only accrue to households, which can afford to pay for the energy supply in the grid. However, this impact less on houses that are not connected to the dries due to financial constraints (Mvondo, 2010). The Free Basic Electricity (FBE) policy was intended as a possible solution to South Africa's electrification challenges. "The FBE policy was derived from a Government decision that was made two years prior to provide basic services to poor households, with priority focused on water, energy and sanitation services" (DoE, 2012). The policy influences municipalities and goverbnment-owned organisatio that are in the electricity sector, to supply a certain amount of free electricity to poor households. 50 kWh is provisioned to households which are already connected, since it is said to be sufficient to satisfy primary energy need. Households which are not part of the grid are provided with "ZAR 40 subsidy per month that is paid towards a ZAR 58 monthly service fee which covers up to 80 % service fee, with the result that these households have to make payments of only ZAR 18 a month" (DoE, 2012).

In many rural areas, earlier studies conducted in the Bushbuckridge proves that even after ten years with electricity , households still use firewood for entries such as cooking. Makonese *et al*. (2018) argues that "the amount of free basic electricity provided to poor households was inadequate to meet basic needs and improvement of quality of life, and proposed a minimum of 200 kWh per month per poor household. Thus, electrification cannot be taken as a single effective solution to reduce the consumption of traditional fuels and reduce impacts associated with their continued use". According to Kanagawa and Nakata (2007), "in poor households, electricity is needed for lighting and refrigeration, and this has been associated with improved education and employment possibilities".

Electricity prices will continue to rise – despite a slowing economy – as supply challenges persist. The short- and long-term outlook for electricity is for prices to increase as Eskom continues to deal with generation and infrastructure costs. Rural households rely on electric stoves because they are stable (and less likely to tip over) and heat evenly via elements, controlled by a thermostat. On an electric cooktop, people can place pots and pans on a completely flat, solid surface. Owing to their flat surfaces, electric stoves are also easier to clean because their smooth, even surfaces can be wiped down easily after cooking has been completed. An extremely efficient thermo-electric device attached to biomass stove can produce 50 to 60 W of DC power. This power can be stored in suitable high-efficiency batteries for lighting. At the same time, part of the power can also be used to run a small fan for cooking stoves. Recent biomass cooking stove designs have shown that air drafts powered by a 5 W battery-driven fan can double the efficiencies of these stoves. Research conducted in **Buffalo City (Eastern Cape)** using a Quality of Life (QoL) survey, "reveal that 92 % of the households had not experienced any cases of illness in the previous nine months" (Mvondo, 2010). The study also indicated that "the electricity usage patterns were related to better health practices" (Mvondo, 2010). For instance, the use of candles has been extremely reduced by the use of electricity. In terms of education, access to electricity has make it easier for students to study positively. Though, there will always be an outcry of children who are spending more time watching TV than studying. (Mvondo, 2010).

2.2.4 Cow dung

According to Muller *et al*. (2003), cow dung is indigestible plant material released onto the ground from the intestine of a cow. Cow dung is high in organic materials and rich in nutrients. It contains about 3 % nitrogen, 2 % phosphorus, and 1 % potassium. Cow dung is used as a rich fertiliser, an efficient fuel and biogas producer, a useful building material, a raw material for paper-making, and an insect repellent. In **India** where Hindus have long worshipped cows as sacred, cow dung cakes have been used for centuries for fires whether for heating, cooking or

Hindu rituals. Across rural India, piles of drying cow dung are ubiquitous. The majority of people in developing countries tend to dry cow dung for fuel use. The dry dung fuel is animal faeces that have been dried in order to be used as a fuel source. It is used as a fuel in many countries around the world. Using dry manure as fuel is an example of re-use of excreta (Muller *et al*., 2003). Cow dung is one of the renewable and more sustainable energy resources through dung cakes or biogas, that replaces household dependence upon charcoal, firewood, firewood and fossil fuel.

The utilisation of dung as a fuel source is represented by other herding societies around the world. Several studies looked at the processing of dung products before they are used as a fuel source. They also examined the preservation of seed remains that might be included in the dung after animal consumption. This includes after the seed and dung has been used as a fuel source and carbonised (Barnes *et al*., 1994). They found out that it is difficult to distinguish the source of carbonised seed remains within the context of a hearth. They also found out that the carbonised seed remains within the ashes but it was difficult to determine if they were found there based on their inclusion in the animal dung or due to regular plant processing before consumption where some seeds might have fallen into the fire. In their research in **Central Anatolia**, Anderson and Ertug-Yaras (1998) also studied dung as a fuel source. They point out that dung is typically a fuel associated with economic or fuel poverty. Within the context of the current study, the use of dung as fuel is representative of extreme fuel poverty. Owing to environmental constraints, such as lack of burnable vegetation, the use of dung as a fuel source is a necessity (Anderson & Ertug-Yaras, 1998).

The demand for cow-dung cakes in developing countries has increased and suddenly the cakes that often found their way into fields as manure have become a thriving business for many. A cow-dung cake which hardly had any demand years ago is now being sold to people. This huge demand is from villagers who cannot afford to buy other fuels for survival. They have also become expensive compared to a few years ago (Anderson & Ertug-Yaras, 1998). Although cow dung is preferred for fuel use, using cow dung as a cooking fuel could expose people to arsenic poisoning. A recent study (Morelli, Cashman & Rogers, 2017) shows villagers on the **Ganga Meghna Brahmaputra** plain were exposed to smoke containing high levels of arsenic every day while cooking. The study says the region’s groundwater is contaminated with the cancer-causing chemical which gets into rice husks through contaminated water. Cattle that feed on contaminated rice husk and water produce dung that is likely to contain high levels of arsenic.

While the dung is burnt in a kitchen, as much as 25 % of the arsenic in the fumes could be absorbed by the respiratory tract of people and lead to diseases such as a persistent cough and chronic bronchitis. The arsenic particles in the air might also settle on food and water and contaminate them. Burning cow dung as a fuel produces a lot of smoke which is harmful for human health and causes environmental pollution. Little heat is produced during burning of cow dung, although burnt dung leaves a large amount of ashes. However, some scientists say the threat is not that serious. They reported that this might not directly affect people because most of the dung-burning ovens are placed out in the open (Muller *et al*., 2003).

2.2.5 Paraffin or kerosene

Paraffin is a flammable liquid which is used in many industries and homes around the world as a fuel for light, heat and power. It is generally non-viscous and clear. However, viscous substances such as wax and other thicker substances can be made from it. Paraffin is also known as paraffin oil or kerosene. It is an incredibly versatile fuel which can be used for many different applications. Since the earliest records of distillation in the 9^{th} century, paraffin has managed to stay with the times. This is especially with the help of those who have discovered improved methods of distilling it and helped shape paraffin into such a robust and reliable fuel which we have at our disposal today (Kituyi *et al*., 2001a; 2001b). In fact, throughout the world today [2020], there are roughly 1.2 million barrels of kerosene used per day for all purposes. A typical oil barrel holds 45 gallons (= 54,000,000 $gallons.yr^{-1}$) or 205 litres (= 246,000,000 $L.yr^{-1}$). The world's total kerosene fuel usage over the course of a year is ~ 19,710,000,000 $gallons.yr^{-1}$. Paraffin is usually transported to rural areas in bulk for purchasing paraffin by the litre or by the bottle. Over 80 % of households in **Djibouti** use kerosene as their primary source of energy for cooking. There are still many people who use kerosene for lighting purposes. **India** has more people using kerosene for lighting than the nine next-highest kerosene-using countries combined, at almost 400 million people. In **Madagascar**, the upper-middle class has become increasingly unable to afford LPG due to a price increase of more than 55 % between 2009 and 2013, therefore being forced to revert to charcoal.

Kerosene burned for lighting is the source of 270,000 tonnes of black carbon per year, contributing the warming equivalent of 240 Mt of CO_2. Although it is preferred in urban and rural areas, it has negative impacts in households. It is highly flammable, as a result it causes a large number of fires and deaths every year. This is caused mainly by careless handling and usage of cheap devices that lack safety features. Fuel spillages, refilling while the burner is running and knocking over the stove while it is burning can lead to disastrous consequences. An inherent problem of wick-type stoves is the heating up of the paraffin reservoir tank during extended periods of use, which can lead to the stove exploding. When paraffin is used in cheap wick stoves, it can produce high levels of pollutants and can contribute significantly to indoor air pollution and ill health (Anderson & Ertug-Yaras, 1998). Paraffin releases high levels of emissions due to the appliances being used in small, enclosed households and issues related to the storage of paraffin that lead to the accidental ingestion of paraffin. Paraffin releases hexane and benzene gases that are harmful to human health. Ingestion of kerosene is harmful and can be fatal. Kerosene is sometimes recommended as an old folklore remedy for killing head lice, but health agencies warn against this type of kerosene use due to the risk of burns and serious illness. When burning, some paraffin lamps emit fine particles such as carbon monoxide, formaldehyde, polycyclic aromatic hydrocarbons, sulphur and NO_x. These by-products may reduce lung function and increase the risks of asthma and cancer in humans. Paraffin is regarded as a cheap fuel to use. The affordability of paraffin stoves has been seen as the driving factor for using paraffin as a primary fuel source across the world. Nevertheless, many households use a combination of firewood and paraffin to keep expenses low. It is also seen as an alternative stand-by technology for urban electricity users in case of power cuts. Paraffin can be bought in small quantities and thus is affordable for poorer families (Gevaart-Durkin, Swart & Chowdhury, 2014).

2.2.6 Gas

Many fuel gases are composed of hydrocarbons such as methane or propane, hydrogen and carbon monoxide. Such gases are sources of potential heat energy or light energy that can be readily transmitted and distributed through pipes from the point of origin directly to the place of consumption (Aneja *et al*., 2001). Using alternative fuel sources such as gas also helps to reduce the negative environmental effects. Many studies reported that gas is reliable. They stated that, on a global basis, in some countries there is an abundance of LPG and other liquid fuels which can be simply imported. A substantial amount of LPG is also produced locally from indigenous coal and natural gas and as a by-product of refineries. This means that the increases in demand can be met faster and more efficiently than is possible with other solid fuels.

Bertschi *et al.* (2003) reported that South Africa has a well-established LPG supply infrastructure and the industry continues to invest in supply capacity to ensure regular and reliable supplies. LPG is available from numerous retail shops, garages and dedicated LPG retailers. When there have been major LPG shortages in South Africa, they occurred because the refineries have gone down or because of distribution constraints such as a shortage of gas cylinders. From a national perspective, gas is cheaper and more affordable when comparing it with the cost of other fuel types. The costs for the average household are in the region of ZAR 60 to ZAR 90 per month, depending on the size of family and the amount of cooking (Muller *et al*., 2003). LPG is clean, non-poisonous and safe. All LPG appliances supplied in South Africa are tested and approved in accordance with SABS standards and are completely safe when used according to manufacturers' instructions.

The Liquefied Petroleum Gas Association of Southern Africa (LPGSA) promotes safety in the industry working closely with fire departments in the control and approval of all LPG sites and with the SABS with regard to installation and operational Standards, Codes and Practices. LPG is supplied in high quality and safe cylinders that are inspected regularly and maintained by gas distributors. It is odourless but given an odour by manufacturers in order for it to have a distinctive smell so that leakages can be identified easily. This is to ensure that safe operating and community protective practices are maintained (Marufu *et al*., 1999). LPG is well suited for use indoors because it is inherently clean and burns without smoke or residual particulate matter. It has a lower carbon content than gasoline, diesel, kerosene and ethanol. It is highly controllable and efficient with instant heat and immediate heat reduction for faster, more economical cooking. It is versatile and can be used in a variety of applications from cooking and heating to refrigeration and even lighting. LPG stoves provide instant heat and are more energy efficient because they offer a greater control over the temperature.

2.3 Impact on Air Quality of Burning Wood for Domestic Purposes

The impact of domestic emissions on air quality is affected by a number of factors, including the magnitude of emissions; the type of emissions; the time of day when emissions occur, and the prevailing meteorology of the area. Domestic emissions are low level and mainly emitted in the early morning, late afternoon and late evening (The wind speed tends to decrease after sunset because at night the surface of the Earth cools much more rapidly than does the air above the surface) when wind speeds are lower and the atmosphere tends to be stable (Hofstad *et al*., 2009) This results in pollutants being trapped close to where they are emitted. Wesley *et al*. (1996) stated that air quality in rural areas all over the world, particularly in developing countries, may be more polluted than in some urban areas. The quality of indoor air is of concern because population exposure to air pollutants occurs mostly within buildings, particularly within the home, and because poor indoor air quality has been related by occupants to complaints of adverse health and discomfort. The WHO (2016a; 2016b) states that over 98,000 Nigerian women die annually from use of firewood. If a woman cooks breakfast, lunch and dinner, it is equivalent to smoking between three and 20 packets of cigarettes a day. Accordingly, the WHO (2016a; 2016b) points out that rural women and children carried on the women's backs are the most vulnerable to inhaling toxic air pollutants from firewood. Smoke is one of the greatest health risks of wood fuel, especially when it is burnt indoors. High temperature and humidity levels can also increase concentrations of some pollutants. Household air pollution is the single most important environmental health-risk worldwide, with 4.3 million deaths each year from pulmonary diseases, strokes, lung cancer and ischaemic heart disease related to cooking with solid fuels including coal and biomass (WHO, 2016a; 2016b).

Source: Wang *et al*. (2016)

Figure 2.3: A picture showing the emission of solid fuel smoke into the environment

In **South Africa**, the worst cases of poor air quality arise from the combustion of wood, animal dung or coal. Use of biomass fuels like firewood for cooking or heating leads to high levels of indoor air pollution especially when burned on traditional stoves or in open fires indoors. These fuel types burnt in open fires, in poorly ventilated low-income households provide energy for cooking, heating and lighting. Large quantities of particulate matter are released from combustion processes and are often responsible for the illnesses experienced by the inhabitants of these households (Grieshop, Marshall & Kandlikar, 2011). The smoke generated by solid fuels burning and domestic wood heating can have significant impacts on air quality, with associated health and environmental concerns. Many communities are located in valleys that are subject to temperature inversions and periods of stagnant air that can trap smoke emissions from wood-burning appliances and other sources close to the ground. These inversions are most frequent in autumn and winter when emissions from wood heating are also greatest. Two of the principal gaseous pollutants in wood smoke are CO_2 and NO_x: they add to the atmospheric levels of these regulated gases emitted by other combustion sources. The main air-quality concern relating to domestic wood heating is exposure to airborne particulate matter at concentrations that could lead to adverse human health and ecosystem effects (Marufu *et al*., 2000).

Another source of trace gases and aerosol is the burning of wood for energy. Although bush fires have been investigated, research on the use of domestic fuel is minimal. Each household fire may be small but, collectively, they emit a continuous supply of products into the atmosphere throughout the year. Paul (2006) suggested that besides emissions from burning, there are also biogenic sources that needs to be accounted for in photochemical grid models, as most types are widespread and ubiquitous contributors to background air chemistry. Other domestic wood-smoke impacts include impairment of visibility by smoke, odorous smoke emissions and emissions of toxic air pollutants such as polycyclic aromatic hydrocarbons (PAHs). Previous studies suggested that wood-stove use worsens air quality on both the inside and outside because wood smoke does not rise and spread during winter temperature inversions. It hangs close to the ground and enters neighbours' yards and houses, schools and hospitals. It is evident in **Tshandama Village** (in Limpopo Province) that downwind areas, areas with temperature inversions and valleys with poor air circulation are most affected. The reason being that wood-smoke particles are so tiny that they remain in the air for long periods and readily enter buildings with incoming cold air (Wesley *et al*., 1996). The air quality offsets as a condition in the Atmospheric Emission Licences of several facilities in 2015, was implemented by the Department of Environmental Affairs, as a response to the huge impact of domestic fuel-burning emissions. It is the first ever legally enforceable measure to be introduced. The Air Quality Offsets Guideline published in terms of the National Environmental Management: Air Quality Act (RSA, 2016), defines "air quality offsets" as:

an intervention, or interventions, specifically implemented to counterbalance the adverse and residual environmental impact of atmospheric emissions in order to deliver a net ambient air quality impact within. But not limited to the affected air shed where ambient air quality standards are being or have the potential to be exceeded and whereby opportunities and need for offsetting exist.

2.4 Negative impacts of Domestic Wood Burning

2.4.1 Impacts of domestic wood heating and cooking on human health

The indoor air pollution (IAP) remains a potentially large global health threat. Health impacts depend on a range of parameters related to fuel properties, the type of stoves used, the kitchen environment and cooking behaviour. Generally, emissions from burning firewood have a greater negative impact on health than charcoal or LPG which are considered relatively clean-burning fuels. Domestic pollution is relevant to health because people spend most of their time indoors. The National Human Activity Pattern Survey (NHAPS) showed that

Source: Naidoo (2014).

Figure 2.4: A picture illustrating how people could be affected by smoke-related illnesses

The use of biomass as a source of energy has many implications for development of household and health. A lot of time is wasted on the collection of biomass: mainly women and children perform this activity and opportunity cost of this time blocks the development of these families (Kanagawa & Nakata, 2007). Poor housing conditions lead to more diseases, thus increasing medical expenses. The World Bank (2012) is concerned about the negative impact of the use of firewood on women and children. The gaseous and particulate emissions associated with domestic-burning activities tend to have a localised impact due to their low dispersion potential and short residence times. For this reason, they are deemed hazardous substances in light of human health. Domestic-burning activities have an impact on indoor air quality (Cooke & Shope, 2005). Mestl *et al*. (2007) indicate that indoor air pollution (IAP) from solid-fuel use in developing countries is estimated by the World Health Organisation (WHO, 2016c) to be the eighth leading health risk worldwide. This leads to various health problems such as acute respiratory diseases, cardiovascular diseases, chronic obstructive pulmonary disease, different types of cancers, tuberculosis as well as many cases of asthma and pneumonia in children. Based on estimates of solid-fuel use for cooking in 2012, exposure to household air pollution caused 4.3 million premature deaths that year. Of those deaths, 3.8 million were caused by non-communicable diseases. Household air pollution is estimated to cause 25 % of all deaths from stroke, 15 % of deaths from chronic heart disease, 17 % of deaths from lung cancer, and more than 33 % of all deaths from chronic obstructive pulmonary disease in low- and middle-income countries. The most significant health risks are associated with the finest particles, in particular respirable particles < 2.5 micrometres (μm) in diameter, termed $PM_{2.5}$.

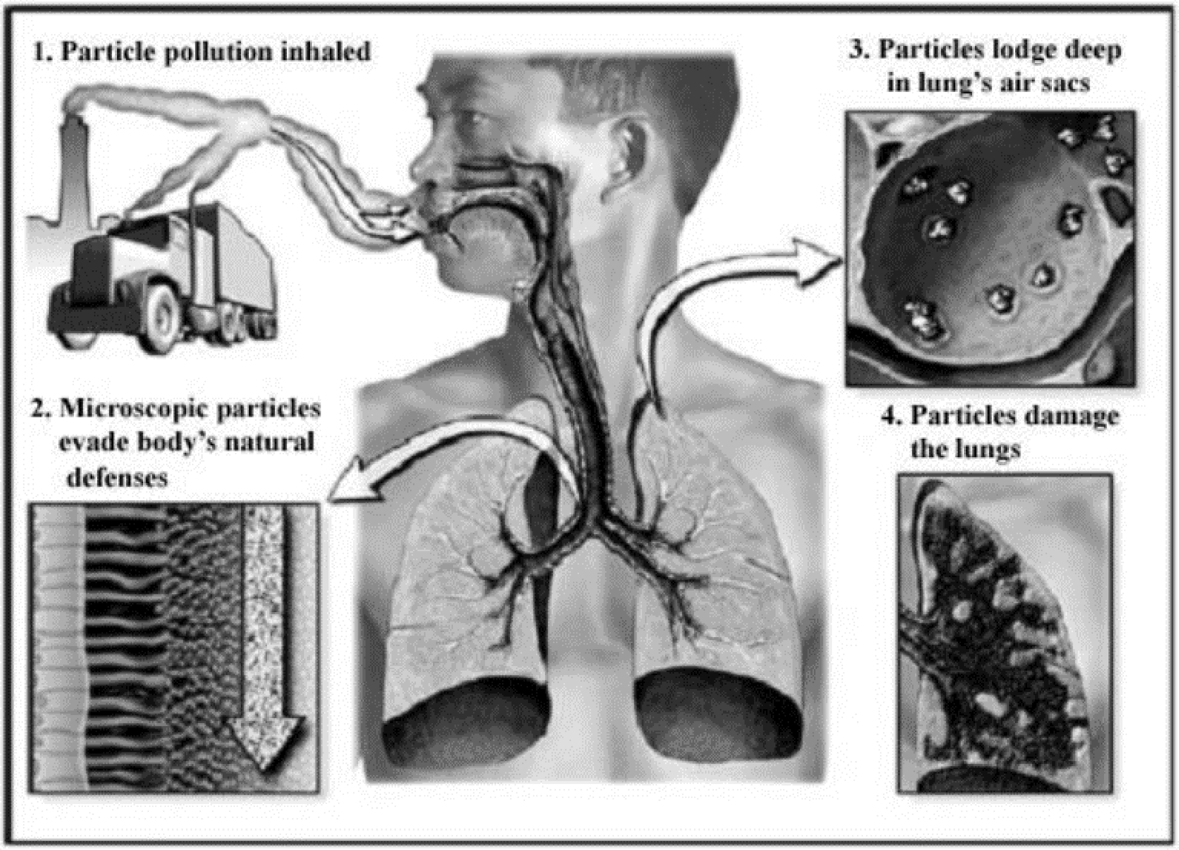
Recent studies have shown that the use of biofuels in traditional stoves leads to the emission of pollutants that have several adverse outcomes on the health of women and children. The World Health Organisation (WHO) asserts that approximately 2.5 million women and young children die prematurely each year because of health problems caused by burning biomass for cooking. Stoves are usually located indoors, with inadequate ventilation. In many cases, small children are often in proximity to the mother as she prepares the meal. The smoke emanating from the stove thus affects not only the cook but her young children as well. Researchers have found that many people believe that since wood smoke is a natural substance, it is not harmful. The amount of wood smoke we breathe depends on how much time we spend outdoors during smoky conditions and how much smoke is indoors when we are there. In houses where wood is not burnt fine particle levels are usually lower than outdoor levels. But, in areas with high levels of wood smoke, even houses not using wood stoves or fireplaces have higher indoor wood smoke levels (Miah, Ahmed & Uddin, 2003). Indoor levels of fine particles from wood smoke in homes without wood stoves can be 50 to 70 % that of outdoor levels, according to a study in Seattle (Li *et al*., 2006). Both draughty houses and air-tight houses with indoor or outdoor air exchange allow wood smoke to come inside. During winter months, Seattle residents spend roughly 90 %

of their time indoors. The median amount of outdoor fine particulate pollution that penetrated indoors and remained suspended in the air was concluded to be 64 % (Wang *et al*, 2012).

Wood smoke contains tiny particles and gases that can have serious adverse health effects when inhaled. When people use wood stoves and fireplaces, chemicals are released into the air and some of these chemicals are toxic. Residential wood-burning greatly increases the number of fine particles in the air. About 42 % of the PM_{10} during winter months could be attributed to wood burning (Miah *et al*., 2003). Rural areas of developing countries suffer the greatest exposure globally to particulate matter and other combustion emissions (Barnes *et al*., 1994). Although wood-smoke particles are usually within the size range thought to be most damaging to human health, their chemical composition is different from particles derived from fossil-fuel combustion.

Meyer *et al*. (2006) and Meyer (2006) stated that breathing air contaminated with smoke from wood results in the inhalation of fine particles which can penetrate deep into the lungs. The particles contain toxic substances that can remain in one's lungs for months, causing changes that lead to diseases and structural damage. Both size and chemical composition dictate the residence time of the pollutants in the atmosphere and, in relation to this, whether the particle is inhalable. Trevor, Antony and Jindal (2013) note that amongst inhalable particles, the extent to which these particles have a negative effect on human health is dependent on a different set of criteria. These include where the particle settles and how long it is preserved in the lung. Figure 2.5 shows the process through which inhalable particles are deposited in human lungs.

Numerous scientific studies indicated that wood smoke is especially harmful to infants and children, the elderly, and people with lung and heart disease. "Approximately 17 % of premature lung cancer deaths in adults are attributable to exposure to carcinogens from household air pollution caused by cooking with kerosene or solid fuels like wood, charcoal or coal" (Meyer, 2006). The role of women in food preparation, exposes them to high risk. Women spend an average of "three to seven hours per day near the stove to prepare food" (Meyers, 2006). Young children are often carried on their mothers' backs or kept close to the warm hearth. During an infant's first year of life their exposed to smoke, their developing lungs make them particularly vulnerable to hazardous pollutants.



Source: Naidoo (2014).

Figure 2.5: The health effects of air pollutants on the respiratory system

Several studies in the 2000s have found that infants born to mothers exposed to solid fuels during pregnancy had higher rates of low birth mass, stillbirth and pre-term birth. Rehfuess, Bruce and Smith (2011) found that mean birth masses of infants born in homes using solid fuels (biomass and coal) and kerosene are substantially lower than mean birth masses of infants in households using LPG. Adetona *et al*. (2013) established that women in Trujillo, Peru who cooked exclusively with firewood or kerosene had higher exposure to Polycyclic Aromatic Hydrocarbon (PAH) compared with women who cooked with LPG or coal briquettes. A study carried out in **Jumla, Nepal** shows that 8 hours and 24 hours total suspended particle (TSP) and carbon monoxide (CO) concentrations were found to be 8420 $\mu g/m^3$ and 13.5 ppm; 5000 $\mu g/m^3$ and 23.42 ppm, respectively (Adetona *et al*., 2013). WHO (2016b) highlights that "children often spend their time near their mothers while they are engaged in cooking tasks".

The single biggest killer of children < 5 years old worldwide is pneumonia. This disease cuts short almost a million young lives each year. More than 50 % of those pneumonia deaths are caused by exposure to unhealthy air pollution. Children inhale more air in proportion to their size than adults (Rehfuess *et al*., 2011). The lungs of this segment are also still developing and, because of this, children can experience more adverse health effects from polluted air than adults. A group of children who was hospitalised with acute respiratory illnesses was studied from birth to 24 months of age along with controls who were not hospitalised. Of the hospitalised cases, 63 % had wood stoves in their homes, compared with 51 % of the controls. Other studies have found that the use of wood-burning stoves increases the risk of lower respiratory tract infections such as bronchiolitis and pneumonia in young children. Childhood lower respiratory tract infections decrease lung function in children during vegetation fire episodes, compared with pre-episode measurements. Globally, "more than 4 million people die prematurely annually due to respiratory diseases caused by inhalation of pollutants from firewood combustion" (Meyers, 2006). The WHO (2016a; 2016b, 2016c) estimated that, "in 2010, about 3.5 million premature deaths were caused by household air pollution (HAP), resulting primarily from cooking with solid fuels". They also estimated that "there were 500,000 deaths from outdoor air pollution caused by household solid fuels used for cooking in developing **Asia** and **Sub-Saharan Africa** (SSA) in the same year". Women and children are mostly exposed to health risk due to pollution. WHO (2016) identifies respiratory infections as the leading cause of death for children. Respiratory infections are the leading cause of death of young children worldwide. According to the World Health Organisation (WHO), nearly half of the deaths among children due to acute respiratory infections (ARIs) are because of indoor air pollution (IAP). Research proves that acute respiratory infections (ARIs) kill 940,000 children under five years of age annually (Muller et al, 2003). "The burden of ARIs in developing countries is considerably higher than that in developed countries" (WHO, 2016). In **India** in 2010, 24 % of the total deaths among children under five years old was due to ARIs. In terms of incidence, 151,000,000 new ARI cases occur annually among children under five in developing countries (Adetona et al., 2013). Many of these result in the death of young children. For example, in **India**, about 160,000 male children and 210,000 female children below the age of five died due to ARIs in 2005. Muller *et al.* (2003) stated that people with existing heart or lung conditions, as well as smokers, ex-smokers and passive smokers, have less resistance to the effects of wood smoke. These people may have more severe symptoms of their existing conditions (for example, wood smoke aggravates asthma, emphysema, pneumonia, and bronchitis). Those with poor lung function, asthmatics and other respiratory problems increase the prevalence of respiratory symptoms and various asthma indicators. These conditions decrease lung function. Older adults are at greater risk of adverse results from exposure to wood smoke if they have concomitant chronic health problems, which can be exacerbated by exposure to fine particles. They can be exposed easily to coughing, oxidative stress, irregular heartbeat, non-fatal heart attacks and premature death. Studies show lower heart-rate variability when people inhale increased levels of particulate air pollution. Young people and older adults are more susceptible to this (Jones, 1999). Household air pollution can sometimes lead to blindness. Women and children, in particular, face higher risks from exposure. Malnourished people and those with nutrient deficiencies are prone to suffering from diseases induced by poor air quality (Sumpter & Chandramohan, 2013). One in four (25 %) premature deaths from chronic obstructive pulmonary disease (COPD) in adults in low- and middle-income countries is due to exposure to household air pollution. Women exposed to high levels of indoor smoke are more than twice as likely to suffer from COPD as women who use cleaner fuels and technologies. Among men (who already have a heightened risk of COPD due to their higher rates of smoking), exposure to household air pollution nearly doubles that risk. Of all premature deaths due to stroke, 12 % can be attributed to daily exposure to household air pollution arising from cooking with solid fuels and kerosene. In India alone, ~ 1,040,000 premature deaths and ~ 31,400,000 disability-adjusted life years (DALYs) are attributed to HAP resulting from solid cooking fuels (Sumpter & Chandramohan, 2013). IEA (2010) projected that by 2030 premature deaths associated with burning biomass indoors will exceed those due to HIV/AIDS. Approximately 11 % of all deaths ascribed to ischaemic heart disease (accounting for > 1,000,000 premature deaths annually), can be attributed to exposure to HAP.

2.4.2 Other impacts of domestic wood heating and cooking on households

Many householders in Matlwang Township complained about firewood smoke staining wet clothing when it is hung in the kitchen to dry. They asserted the smoke discolours the kitchen and other house walls. Smoke also causes householders' clothing to smell of firewood smoke.

2.5 Preferred Tree Species for Firewood in Rural and Urban Areas

According to Freudenberger *et al.* (2004) all wood is chemically similar regardless of species. It is mostly the density and moisture content that influence its behaviour in a fire and its value as firewood. Dense hardwoods (like maple and oak) have a higher energy content per cord and so release more heat per firebox load. They also produce long-lasting fires and coal beds. Softer woods (like birch, pine, spruce and poplar) are less dense, burn faster and do not produce a long-lasting coal bed when burned. Traditionally, hardwoods have been the preferred firewood, especially in central and eastern **North America**, although softer woods make excellent fuel for spring and fall use. Those who heat with wood in the coldest parts of **North America** have only softwoods (like spruce and pine) and light deciduous trees (like birch and aspen) to burn and they still manage to stay warm. The newer, more-advanced technology wood stoves, fireplaces and furnaces can function well with a wide variety of wood species because of their better control of the combustion process than older, conventional stoves (Mucina *et al*., 2006).

2.5.1 Senegalia ataxacantha

The *Senegalia ataxacantha* [previously *Vachellia ataxacantha*] species [the flame thorn tree] grows very slowly and its preferred habitat is deep, dry sandy soils. Its habitat helps to protect against salt spray, sand blast and erosion of soil at the roots. When sheltered from the wind, it tends to grow into a small tree (up to 7 metres high) (Mucina & Rutherford, 2006). This tree species normally flowers in one brief, but impressive, display and giraffe and camels commonly graze on the harder-to-reach succulent leaves normally out of reach of smaller animals. Giraffe, especially, are partial to **all** *vachellia* [*vachellia karroo* sweet thorn, "mooka" (Northern Sotho)] and manifest a specially adapted tongue and lips that can cope with the vicious thorns. The wood from this tree species is dark reddish brown in colour and extremely dense and strong. It is a good fuel for fires which leads to widespread clearing of dead trees and the felling of healthy trees. *Senegalia ataxacantha* produces good flames when it burns. The species yields a hardwood and is often used in smaller domestic items as walking sticks, handles, spears and tool handles, particularly in South Africa. In traditional medicine, the bark is used for headache and toothache. Root infusions are used for leprosy, syphilis, and coughs, as an antihelminthic, purgative and strong diuretic. The leaves are used for epilepsy and also as a diuretic and laxative (De Fries, Foley & Asner, 2004). The roots are also sometimes used for bites or stings as they are rich in nutrients. The plants are often used as fertiliser and for soil conservation.

2.5.2 Podocarpus latifolius

Hahn (1994a; 1994b) defined *Podocarpus latifolius* [yellowwood] as an evergreen tree which grows between 20 m and 30 m in height. Under some conditions, the tree does not grow more than about 2 m but looks very old and full of character. The wood is yellow with greyish bark and smooth when young but shows the characteristic longitudinal fissures as it matures. *Podocarpus latifolius* produces good flames when it burns. The bark peels off in strips. It has long and narrow green leaves. The leaves on young trees are always larger than on mature trees. The new leaves are very noticeable as they form clusters of pale green or bronze at the ends of branches compared with the dark green of the older leaves. In the past, *Podocarpus latifolius* were so sought after as timber trees that, having once been an abundant resource, they became almost extinct in some areas. Yellow-wood furniture commands high prices because of its rarity.

The indigenous yellowwood grows naturally in mountainous areas and forests in the southern, eastern and northern parts of South Africa. It is also found on rocky hillsides and mountain slopes but does not grow as tall where it is exposed as it does in forests. Apparently, it has been used more than any other South African timber. An unusual use was that of a butcher's block because the wood is hard and did not chip easily. It also has no scent, so it cannot taint meat or fish (Freudenberger *et al*., 2004).

2.5.3 Ficus sur

Ficus sur is a fast growing, evergreen tree that usually reaches 5 m to 12 m in height but it may sometimes attain a height of 35 m to 40 m. Over its extensive range it is variable with respect to leaf shape, texture of the leaves and figs, deciduousness and overall size. The tree species is found in forests or grassy woodlands, and occurs at higher densities in well-watered temperate uplands. The bark of younger trees is smooth and pale greyish white in colour. The wood is light and soft, and it is not used much commercially. *Ficus sur* produces good flames when it burns. All parts may exude latex which has some traditional medicinal applications. The latex may be effective in cancer treatment, while a methanolic extract from the roots is potentially effective against chloroquine-resistant malaria. The wood from this tree species needs to be split into small sections and given plenty of time to dry to produce a good flame. *Ficus sur* is good for barbecues (Mucina & Rutherford, 2006).

2.5.4 Brachylaena transvaalensis

Brachylaena transvaalensis [previously *Brachylaena discolour* subsp. *Transvaalensis*] is a shrub or tree that grows up to about 10 metres tall. It is known to reach 27 to 29 metres at times. The branches are brown or purple tinged, and hairy when new. Its leaves are oval and usually up to 120 millimetres long. The leaves are mostly hairless and are a shiny dull green on top and greyish hairy underneath. *Brachylaena transvaalensis* grows in coastal forests and along rivers. Its flowers produce abundant nectar and attract insects and birds. The plant nectar produces a good honey. The leaves may be browsed by antelopes such as nyala, bushbuck, and duikers. The wood from this tree species is strong and it has been used for many purposes including the construction of boats, housing and roofing, fences, axles, tools, and "knobkerries" [clubs with a large round ball at one end of the stick]. It is considered a valuable carving wood. Its wood produces good flames when burnt. *Brachylaena transvaalensis* can be used in the production of soap. The plant has been used to treat kidney conditions, diabetes, gastro-intestinal bleeding, intestinal parasites, and chest pain (Freudenberger *et al.*, 2004).

2.5.5 Englerophytum magalismontanum

The *Englerophytum magalismontanum* species is an evergreen tree with a small, rounded crown. It can grow from 6 to 45 metres tall. This species is usually found in areas where the minimum annual rainfall is about 600 mm. The flowers are a good source of nectar for bees. The heartwood is white to light brown, often with purplish streaks. It is not differentiated from the sapwood. It has a fine texture, and produces hard and heavy timber. It is not durable and not resistant to termite attack (Brown *et al*., 1996). The wood needs to be dried slowly to produce a good flame. The wood is suitable for indoor purposes requiring great strength and elasticity, such as flooring. Sawing the green timber is difficult because of its tendency to "spring", but the dry wood is easier to work. The wood produces good flames when it burns. It is moderately easy to work using hand tools and has excellent machining properties, especially in moulding, but it may have an appreciable blunting effect on tool edges (Hahn, 1994a; 1994b).

2.6 Causes of Climate Change

"Climate" is the weather conditions prevailing in an area in general or over a long period. Hay (2002) defined "climate" as expected weather. When changes in the expected weather occur it is called "climate change". Climate change can also be defined by the differences between average weather conditions at two separate times. Climate may change in different ways over different time scales and at different geographical scales. In recent times, scientists have become interested in global warming due to mankind's impact on the climate system through the enhancement of the natural greenhouse effect.

2.6.1 Deforestation

Climate change is mainly caused by the production of greenhouse gases from anthropogenic activities; including agricultural production, industrialisation, burning of fossil and bio-fuels, and deforestation. These gases react with the thin (ozone) layer which protects the Earth from direct heat from the sun. When this layer is depleted, sun rays hit the Earth's surface directly, resulting in temperature rises that influence climate on the Earth and these changes manifest as global warming, prolonged droughts and unreliable rainfall. The developed countries (particularly **China**, **United States of America** and **European Union** member states, among others), are the largest producers of these emissions and hence the largest contributors to climate change. Ilori *et al.* (2000), defined "deforestation" as "the removal or damage of vegetation in the forest to the extent that it no longer supports its natural flora and fauna". Deforestation is "a permanent change of land use from forest to other land use or depletion of forest crown cover to less than

10 %” (FAO, 2006). Clear cuts, if shortly followed by reforestation for forestry purposes are not considered deforestation, whereas forest degradation is the impoverishment of standing woody material caused mainly by anthropogenic activities such as over-grazing, over-exploitation (for firewood in particular), repeated fires, or due to attacks by insects, diseases, plant parasites or other natural causes (such as cyclones). Both processes of deforestation and forest degradation are associated with release of greenhouse gases into the atmosphere (Bajgain & Shakya, 2005).

The accelerating destruction of the rainforests, that form a precious cooling band around the Earth’s equator, is now being recognised as one of the main causes of climate change. Forests generate the bulk of rainfall worldwide and act as a thermostat for the Earth. When forests are felled or burned, the CO_2 stored by the trees escapes back into the air, thus creating change in climate (Urmee *et al*., 2009). Since humankind evolved, trees provided necessities such as shelter, energy, medicine and tools. Today, their value continues to increase and change in some ways. More benefits of trees are being discovered as their role expands to satisfy the needs created by our modern lifestyles. Trees are an important part of every community. Streets, parks, playgrounds and backyards are lined with trees that create a peaceful and aesthetically pleasing environment.

According to Cooke, Eriksson and Junttila (2012), trees increase one’s quality of life by bringing natural elements and wildlife habitats into urban settings. People and animals gather in the cool shade trees provide during outdoor activities with family and friends, and while resting. Many neighbourhoods are also home to very old trees that serve as historic landmarks and are a great source of town pride. Trees contribute to the environment by providing O_2, improving air quality, climate amelioration, conserving water, preserving soil and supporting wildlife (Kgathi, 1997). During the process of photosynthesis, trees take in CO_2 and produce the O_2 we breathe. According to WHO (2000), one acre of forest absorbs six tonnes of $CO_2$and puts out four tonnes of O_2. This is enough to meet the annual needs of 18 people. Trees are important in removing dust and absorbing other pollutants like CO, SO_2 and NO_2. Equally, trees contribute to the formation of convectional rainfall. Without trees, rainfall will either reduce or will not be there. Leaves of trees absorb and filter the sun’s radiant energy for keeping things cool in summer. They also preserve warmth by providing a screen from harsh wind. In addition to influencing wind speed and direction, they shield us from the downfall of rain, sleet and hail (Mucina *et al*., 2006). Trees also lower the air temperature and reduce the heat intensity of the greenhouse effect by maintaining low levels of CO_2. Both above- and below-ground, trees are essential to the ecosystems in which they reside. Far-reaching roots hold soil in place and fight erosion. They are important for absorbing and storing rainwater which reduces run-off and sediment deposited after storms. This helps the ground water supply recharge, prevents the transport of chemicals into streams and prevents flooding. Fallen leaves make excellent compost that enriches soil (van Wyk, 1996). Demand for fuel destroys forests near villages and towns in many countries. The loss of trees leads to increasing erosion. Where dried dung is used instead of firewood, soil fertility is lost and harvests are reduced. The forests are being cut down faster than they can regenerate. While deforestation benefits some people, it imposes environmental damages on others. One of the most widespread impacts is the effect of forest loss on climate change via increased net CO_2 emissions. These greenhouse effects and the resulting global damages are associated with all permanent forest loss regardless of location (Han & Northoff, 2008; Bajgain & Shakya, 2005).

Deforestation is also a leading cause of global biodiversity loss. It is possible to identify "hotspot" locations where deforestation poses a particularly severe threat to biodiversity. These locations are disproportionately located in the fragmented depleted forests near urban areas (Bhatt & Sachan, 2004). Forests are often thought to prevent floods, aid dry season flows, prevent erosion and sedimentation. According to Urmee et al. (2009) deforestation is a contributor to global warming and is often cited as one of the major causes of the enhanced greenhouse effect. Tropical deforestation is responsible for approximately 20 % of world greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change (IPCC), deforestation in tropical areas contributes one-third of total anthropogenic CO_2 emissions. But recent calculations (De Fries *et al.*, 2004) suggest that CO_2 emissions from deforestation and forest degradation (excluding peat land emissions) contribute about 12 % of total anthropogenic CO_2 emissions with a range from 6 to 17 %. Deforestation causes CO_2 to linger in the atmosphere (Bhatt & Sachan, 2004). As CO_2 accrues, it produces a layer in the atmosphere that traps radiation from the sun. The radiation converts to heat which causes global warming which is better known as the "greenhouse effect".

Deforestation may also cause carbon stores held in soil to be released. Forests can be either sinks or sources, depending upon environmental circumstances. Mature forests alternate between being net sinks or net sources of CO_2. According to Urmee *et al*. (2009). In deforested areas, the land heats up faster and reaches a higher temperature, leading to localised upward motions that enhance the formation of clouds and ultimately produce more rainfall. However, according to the Geophysical Fluid Dynamics Laboratory, the models used to investigate remote responses to tropical deforestation showed a broad but mild temperature increase all through the tropical atmosphere. The model predicted < 0.2 °C warming for upper air at 700 mB and 500 mB (De Fries *et al.*, 2004). However, the model shows no significant changes in other areas besides the tropics. Though the model showed no significant changes to the climate in areas other than the tropics, this may not be the case since the model has possible errors and the results are not absolutely definite.

2.6.2 Increased population

The current [October 2020] world population is 7.8 billion, according to the most recent United Nations estimates elaborated by World meter. The term "world population" refers to the human population (the total number of humans currently living) of the world. The population of South Africa in [2019] was about 58.8 million (Stats SA, 2019). Of this population, 43.9 % lives in urban areas and electricity remains the primary source of power in urban areas. All appliances and gadgets run on electricity generated mainly from thermal power plants. These "thermal power plants are run on fossil fuels and are responsible for the emission of huge amounts of greenhouse gases and other pollutants" (Gautam et al, 2009). Equally, motor industry remains the principal way by which goods and people are transported. These are run mainly on petrol or diesel, both fossil fuels, hence, generating too much CO_2 which is responsible for climate change. According to the DEA (2009) second-hand imported cars and refrigerators in South Africa were the major causes of environmental pollution at that time. Since then, import regulations for second-hand cars have changed and tightened up. This was because gaseous emissions from second-hand cars contributed between 5 % and 15 % of environmental degradation, which was a cause of climate change. Since 2010 freon has not been used in fridges in South Africa as that legislation has also changed.

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A detailed description of the fuel types utilised in rural and urban areas was provided. The climatic effects and the health risks associated with the resulting emissions were also discussed.

CHAPTER 3:
RESEARCH METHODOLOGY

This chapter provides a detailed description of the study site at which this research was conducted. It describes the processes and methodologies involved in conducting this research as well as the materials and instrumentation that were used.

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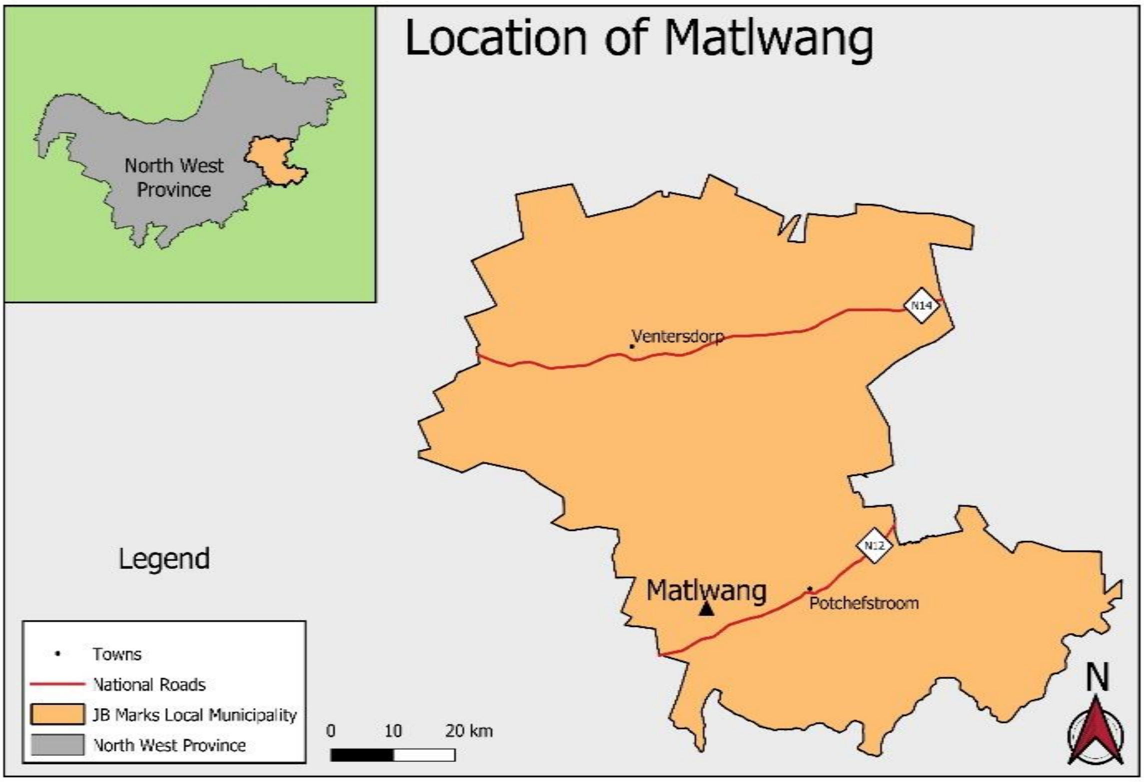
3.1 Study Area

This study was carried out in Matlwang, a township located on the foot of the central and western part of J.B. Marks Local Municipality of North West Province. The North West Province occupies a total area of 116,320 km^2 and is the sixth-largest province in South Africa. It is geographically situated between 25 and 28 degrees south of the equator and 22- and 28-degrees longitude east of the Greenwich meridian (Thorn *et al*., 2012). The North West Province borders the provinces of Northern Cape in the west, Free State in the south, Gauteng in the east and Limpopo in the north-east. Matlwang is one of the richest biodiversity areas in the J.B. Marks Local Municipality. The township has diverse plant species, including trees, shrubs, grasses and lianas. The study area is dominated by tree species such as *Senegalia ataxacantha* and *Ficus sur*; animal species such as mammals, birds and invertebrates. The township lies between the latitudes of 26.78730^o and 26.58154^o and it covers a total area of 14,490 km^2. Its neighbouring towns are Potchefstroom, Stilfontein and Matjabe (Figure 3.1).



Source: Molapo, 2021

Figure 3.1: Map showing the geographic location of the study area

3.2 Research Methodology

The aim of this study was to quantify the use of firewood as a source of energy in the township of Matlwang. Creswell (2003:12) defined **"survey"** as a flexible research approach used to investigate a wide range of topics. Surveys often employ questionnaires as a tool for data collection. Oppenheim (1992:84) defined **"survey"** as a method of collecting data in a consistent way. Survey research is useful for documenting existing community conditions, characteristics of a population, and community opinion. Survey data are not only useful for immediate community development purposes, but they can also serve the future of a community's efforts by providing baseline data needed later to demonstrate progress.

According to Sarantakos (2005; 2007) to increase the validity of survey results, it is important to ensure that participants in the survey process are the stakeholders who are affected by, or involved in, the processes under review in the survey. These persons will be the ones most knowledgeable about the outcomes and impacts of the process and have the most relevant input for improvement. There are several different approaches to conducting a survey. One common approach is the cross-sectional survey, where a set of information is collected for a sample at one point in time. Data may be collected from a sample of the population or from an entire population or community. The longitudinal survey provides another means of looking at changes over time; with this type of survey, the data are actually collected at different points in time. This can be accomplished by either sampling from a population at different points in time, or by following up on a group of individuals at different points in time (Dunn, 2005). Advantages of using surveys is that they are flexible and efficient. They have internal and external validity and they can cover geographically spread samples. Disadvantages of using surveys are that they are dependent upon the chosen sampling frame. They are not good at explaining why people think or act as they do.

The choice of a research methodology is determined by its relevance to the research problem and in answering research objectives. The selection of the appropriate research methodology depends upon a number of factors, including, but not limited to: access to potential participants /respondents; the literacy level of respondents; the subject matter and the motivation of the respondent's resources. A ***"mixed method"*** approach was adopted as the methodology of choice for this research study. The rationale for adopting it was to garner an enriched perspective on the dynamics of solid fuels as well as emissions produced in the area (Hanson *et al*., 2005).

Methods of sourcing data included face-to-face interviews and structured questionnaires. Open-ended questions were used to conduct unstructured face-to-face interviews in the township. Interviews did not follow a set format but rather general, sub-topic questions. An interpreter was hired for both interviews and questionnaires to assist with interpreting some of the questions for the households to understand. Necessary and follow-up questions were asked and the responses were jotted down during the interviews.

Kasperson *et al.* (2003) stated that face-to-face or personal interviews are much more labour intensive but can be the best way of achieving high-quality data. They are preferable when the subject matter is sensitive but not personal. They are also preferable if the questions to be coded are complex or if the interview is likely to be lengthy. Face-to-face interviews can take both qualitative and quantitative approaches. Surveys tend to take a quantitative approach. Interviewers carrying out face-to-face interviews for a quantitative study will use a structured interview schedule. Overall, face-to-face interviews are more expensive than other methods but they can collect more complex information and are also useful when the subject matter is not of particular personal interest to the household who might be unlikely to complete a postal questionnaire. Face-to-face interviews are appropriate if the researcher needs to show anything such as diagrams or where certain disabilities may make completing a questionnaire through another method prohibitive.

Having received an Ethics Clearance Certificate from the Ethics Committee of the Faculty of Agricultural and Natural Sciences (ethics number- 0158720A9), refined, structured questionnaires were distributed to the 50 identified households. All households who met the basic criteria (solid-fuel users living in Matlwang) were identified. The researcher approached the households accompanied by a community leader to discuss the details and aims of the research and to request their permission to conduct questionnaires and interviews. The primary qualification criteria for participating households were formulated and applied to a simple random sampling. The criteria used were: the household had to have indicated that it is interested to participate in the project and the household used solid fuels for cooking and space heating.

The questionnaire was designed to generate data conducive to the goals of the research. The questionnaire format, sequence and wording was designed to ensure reliability, validity and sustained engagement of the participants. Questionnaires were designed with closed-ended questions. Closed-ended or structured questionnaires are questions to which the household selects one or more options from a pre-determined set of responses (Collins, 2003). Closed-ended questionnaires are easy to process and useful for testing specific hypotheses. In close-ended questionnaires, the respondents cannot extend writing. Its disadvantages are that: respondents may be irritated because they are not able to express themselves; researchers are likely to lose spontaneous response(s); respondents may also answer superficially especially if the questionnaire takes a long time to complete. The common mistake of asking too many questions should be avoided (McGuirk & O’Neill, 2005a; 2005b). Related questions were grouped under a short heading describing the theme of the section. The objectives and questions of the study, the target respondents and methods to reach participants and interpretation of results were considered when developing the questionnaire.

Collins (2003) states that “the principal requirement of the questionnaire format is that questions are sequenced in a logical order, allowing a smooth transition from one topic to the next”. This will ensure that participants understand the purpose of the research and they will answer questions carefully to the end of the survey. A questionnaire should allow researchers to collect the most complete and accurate data in a logical flow. This is done to reach reliable conclusions from what the researcher was planning to observe. The researcher should clearly define the target, study populations from which she/he collects data and information desired from the study. Before writing the questionnaire, the researcher should decide on the questionnaire content. Each question should contribute to testing one or more hypothesis/hypotheses / research question/questions established in the research design.

Questionnaire pilot testing may enable researchers to convert an open-ended question into a closed question by determining the range of possible answers. Researchers may also be able to perform a trial analysis on their pilot sample and hence test all their analysis procedures (Collins, 2003). In this study, questionnaires were pre-tested on five community members from Matlwang to detect any shortcomings and to make corrections prior to the main survey being administered. Completion of the questionnaire was anonymous and voluntary for all participants. The target population of the study was residents in the households of Matlwang village. Questionnaires were administered and completed independently by the participants.

3.2.1 Sampling

Households were purposively selected. Sampling involves the selection of a number of study units from a defined study population. The population is too large for us to consider collecting information from all its members. Instead a sample of individuals is selected hoping that the sample is representative of the population (Degu & Yigzaw, 2006). In this study purposive sampling was used to select the households that were interviewed from the population specified above. The households were purposefully selected to represent all households that used solid fuel.

Purposive sampling saves cost and time to a great extent. This method is the most straightforward of all the sampling methods, since it only involves a prior knowledge about the population. A fixed size of fifty households was selected. The use of a fixed number of households was to avoid problems that may arise with proportional sampling.

3.2.2 Data collection

Kasperson *et al*. (2003) stated that data collection allows researchers to collect information that they want to collect about their study objects. Depending on the type of research, methods of data collection include reviewing documents, observation, questioning, measuring, or a combination of different methods. The study was carried out in Matlwang where face-to-face interviews, structured questionnaires and observations were conducted. Questionnaires were distributed to the sampled households to obtain statistically useful information about a topic. The questionnaires were paper-based and the questions were closed-ended. The questionnaires consisted of 27 questions and were issued to 50 households in Matlwang.

Data were collected in the summer and winter seasons of 2017. In ***summer***, data were collected from 05 February to 16 February 2017. In ***winter***, data were collected from 28 May to 08 June 2017. Both campaigns involved the same households for the sake of completeness of information and continuity. For the households' fuel-use survey, each household was asked the same questions in the same way. Households were equipped with a scale (Figure 3.2) and a logbook in which they recorded the mass of firewood they used (burned) at each cooking session (breakfast, lunch and dinner). The total mass of firewood (kg) used was recorded daily. The residents of the household were interviewed to obtain additional information regarding the use of firewood. The data collected were used to calculate daily consumption rates in kg. Necessary and follow-up questions were asked, and notes of responses were taken during interviews.

Source: Own photograph

Figure 3.2: A hanging scale set up in a kitchen of one of the 20 study households in Matlwang, where they recorded the mass of the firewood they used (burned) daily

3.2.3 Data analysis

Microsoft Excel 2013 was used to analyse data. The advantage of Microsoft Excel 2013 is that, it is easy to use, can do simultaneous analyses and is sufficiently powerful to analyse large volumes of data. Its disadvantage is that it is difficult to customise graphs and not easy to share its tools. Before data were analysed, questionnaires were checked individually for completion. This was done in order to discard questionnaires that were insufficiently completed, or where there was evidence that the residents had not taken the task seriously. All questionnaires had been completed diligently and none needed to be discarded. The written results of the questionnaires of this study were entered and coded to the Excel sheet. The data were checked thoroughly, edited and cleaned in order to avoid omissions and mistakes. Data were, therefore, analysed in order to present them in tabular format.

To estimate firewood emissions, the following calculations were made:

- Total emissions from firewood burnt per household (20 households) during the 2017 summer & winter seasons in Matlwang;
- Total emissions from firewood burnt per month per household (20 households) during the 2017 summer & winter seasons in Matlwang;
- Total emissions from firewood burnt per annum per household (20 households) during the 2017 summer & winter seasons in Matlwang; and
- Emission estimates for various gases (CO_2, CO, NO and CH_4) in three burning events per household and township in the 2017 summer & winter seasons.

Emission estimates were calculated as in Equation 1:

$$Emission\ (g\ C\ .\ kg^{-1}) = BC\ x\ MCF\ x\ EF \qquad \textbf{(1)}$$

Where:

BC	*is the*	*Biofuel Consumption rate;*
MCF	*is the*	*Moisture Correction Factor, and*
EF	*is the*	*Emission Factor for the particular gas.*

According to Naidoo (2014) to determine the emissions, as indicated in Equation 1, the method requires that the fuel consumption and the emission factors for that specific fuel are known. This equation states that the emissions of a specific pollutant can be calculated by multiplying the amount of fuel consumed or burnt by the emission factor for that pollutant, for that specific fuel (Naidoo, 2014). The emission factors for both particulate and trace emissions will vary, depending on these different components.

The concentrations of CO_2, CO, NO and CH_4 were calculated for wood, using the emission factors in Table 3.1.

Table 3.1: Emission factors used to calculate emission estimates

	Units	CO_2	CO	NO	CH_4
Wood	**g/kg**	450	43	0.52	1.5
Source: (*Ludwig et al., 2003*),					

The emission factors presented in Table 3.1 were identified specifically for the estimation of domestic fuel combustion. Calculations were done using Microsoft Excel 2013 and the results were presented in Tables 4.9 and 4.10.

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The experimental methods presented in this chapter were used to derive the study results of the consumption rate of firewood as well as the amount of firewood burnt in the households discussed in Chapter 4 to Chapter 6.

CHAPTER 4:
RESULTS & DISCUSSSION

This chapter focuses on the results generated from the field study. The chapter starts by profiling the households, and presents the fuel types utilised in Matlwang, the types of cooking devices, the sources of firewood in Matlwang, the household burning patterns and the mass of firewood consumed in summer and winter in the households of Matlwang. Finally, quantification and estimations of the emissions produced by households in Matlwang are presented.

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4.1 Description of the participating households and their respondents

During the fuel-use survey, questionnaires consisting of 27 questions were distributed to 50 households in Matlwang. Each household selected one member from the household to be the respondent. The respondent was given the responsibility to complete the questionnaire diligently and have it ready for collection by the researcher when she visited again the following week. From the data collected in the township, most households comprise of five members: mother, father and children. Grandparents were also found in some households. There were five types of fuel used for cooking and heating in Matlwang: wood, electricity, cow dung, gas and paraffin. Six cooking devices were commonly used in the township: an inside stove, an outside stove, an Mbaula, an electric stove, a paraffin stove and a gas stove. Three tree species were preferred for firewood in the township: Sweet thorn (Mooka), Broom cluster fig (Moumo) and Mountain peach (Mmilo). At the time of the research there were two collection points for firewood in the township (Kgapamadi and Kgabaesetswe) and three daily burning events. Households in the township burnt firewood in the morning, afternoon and in the evening.

During the survey, a community leader reported that (in April 1995), JB Marks Local Municipality (formerly Tlokwe Municipality) approached the community with a proposal to develop the township. The proposal was to build a park. However, the residents rejected the idea as they did not want the municipality to use their land for such activities because other residents needed space to erect housing.

The Community leader also stated that in June 1995 Tlokwe Municipality approached them again, this time with a proposal to build a game reserve in the township. The residents rejected this idea also as they would not permit Tlokwe Municipality to construct a game reserve in the township because such a project would occupy a large piece of their land. According to the residents, it was not necessary to build a park and/or a game reserve because their land is "rich" in natural resources (such as gold, water, platinum, diamonds and wood for charcoal) which cannot be disrupted. The residents reported that they would not have allowed those projects to exploit their resources. The community leader reported that the township relies fully on, and depends on, those natural resources to better their lives and also the lives of future generations. According to the community leader, some residents work at mines for survival. The community leader also stated that the river in the township supplied water to the residents and to people in Stilfontein Township. He reported that the river is beneficial to the residents as they use water for domestic activities and for irrigation. Average emission estimate factors produced from burning of firewood in the township during the 2017 summer and winter season were also calculated.

4.2 Types of Fuel Used in Matlwang Township

The households in Matlwang in 2017 used five types of fuel for cooking and heating (Table 4.1).

Table 4.1: Fuel types used in Matlwang township as determined from the household survey in February 2017

Fuels used in Matlwang	Percentage of households using the fuel type
Wood	86 (n=43)
Electricity	72(n=36)
Cow dung	28 (n=14)
Gas	2(n=1)
Paraffin	10(n=5)
Total number of households that participated in the survey: 50	

N.B: The percentages presented are based on the number of households that indicated that they used a specific type of fuel. In most cases households used more than one type of fuel, hence the percentages do not total 100 %.
Source: Own compilation.

Of the 50 households that participated in the survey all of them indicated that they use a combination of at least two sources of energy. Of the 50 households, 43 of them claimed to use firewood for cooking and heating and 36 households indicated that they use electricity for cooking and lighting. Fourteen households claimed to use cow dung at certain times, mainly during wintertime, due to its superiority for heating the house. Five households claimed to use paraffin for cooking. Only one household claimed to use gas for cooking.

None of these data were verified but are what the individuals reported. According to the data provided in Table 4.1, the two major sources of energy used in the township have been identified as firewood and electricity. Although these two fuels are preferred in the township, wood remains the most preferred type of fuel in the township. This is evident in Matlwang during the summer and winter seasons where low-income households favour firewood because it is readily available and inexpensive. Available burning wood as a heating source can be quite satisfying. Wood is also most preferred as a fuel since it does not produce as much smoke as cow dung and charcoal. Dry firewood is cleaner to burn and causes less smoke and air pollution (with fewer associated health problems) than wet wood (Kituyi *et al*., 2001a; 2001b). However, burning wood can also be quite dangerous if not properly managed. Obvious problems with operating hot stoves aside, burning wood causes creosote to form in stove pipes and exhaust systems. Creosote fires can be extremely dangerous and usually lead to major house fires (Yevich & Logan, 2003).

Most households who use electricity in the township stated that they use it for lighting, although other households use it for cooking and space heating. The majority of households reported that electricity is expensive and they cannot afford to use it for cooking, boiling water and lighting in daily life. However, households stated that they preferred using electricity because it is safe and user friendly. Concerns about affordability or other factors mean these households may still use kerosene for light when the power cuts out, or in other rooms or spaces without an electric light. Global lighting trends are characterised by deep inequity: those without access to electricity spend up to 1000 times more per unit of light than those who have a reliable electricity supply. The poor spend far more, as a proportion of their income, in light of far lower quality illumination than the rest, totalling around USD 40 billion per year worldwide (Mills, 2005). There are serious health consequences of this lighting gap. While much of the focus in the global development community is on the importance of extending electricity access for economic productivity, there are substantial health and environmental benefits to be realised from transitioning households to electric lighting and other clean lighting fuels. Fuels such as cow dung, gas and paraffin are commonly used by households to replace wood and electricity. Of households who preferred cow dung as a fuel type, 28 % stated that they preferred it because it is cheap, available and accessible. These households have a large portion of the unemployed population and poverty is rife and therefore have to rely on less convenient, and often harmful, fuels (Balmer, 2007). Most households in the township own cattle, which makes it easy for households to replace firewood and electricity with cow dung for cooking and heating the house. The households reported that cow dung produces a large amount of ash which warms their house in the evening during winter. Yevich and Logan (2003) opined that dung is typically a fuel associated with economic or fuel poverty. Paraffin and gas fuels are usually utilised in warmer, summer months. Of the households who used paraffin for fuel, 10 % also stated that they preferred paraffin because it is cheap and is also sold in the township. Paraffin is the most common complimentary fuel within completely un-electrified settlements as it is used largely for cooking and also for lighting by means of paraffin lanterns (Gupta *et al*., 2001). Of households who used gas, 2 % stated that they preferred gas because it is fast and clean. Gas is well suited for use indoors because it is inherently clean and burns without smoke or residual particulate matter. It has a lower carbon content than gasoline, diesel, kerosene and ethanol (Balmer, 2007).

Matlwang households also reported that electricity is not sold in the township and, in order for them to go to buy electricity in the nearest city (Potchefstroom), they need to pay the taxi fare of ZAR40 per person for a return journey. From her observations, the researcher concluded that the travelling distance for buying electricity is also a limiting factor in the township because the households cannot afford transport fees and also money to buy electricity. Some households reported that their households do not have electricity. As a result, they cannot use an electric stove as the cooking device. Menash (2001), states that “energy poverty does not mean solely that some people cannot meet their needs for food and warmth, but it is also difficult for them to grab opportunities to develop”. According to recent data, about 1.4 billion people, globally, are without access to electricity (Marufu et al. 2000). Even though South Africa possessed large electrification rates, Ferriel (2010) noted that, in total, there are "approximately 2.5 million rural and urban South African households that are not connected to the national electricity grid, in addition to the millions who are connected to the grid but are unable to pay for electricity". It is a struggle for households with low income to afford electricity and sustain their lives (Mapako & Prasad, 2005).

4.3 Types of Cooking Devices Used in Matlwang Township

Households use several types of cooking stoves and these stoves are often associated with specific energy types (Table 4.2). For example, the traditional (3-stone) fireplace is associated with coal and/or wood burning between the stones to heat a pot of food on top of a griddle. Simple non-traditional, chimney, rocket, charcoal and gasifier stoves use solid fuels which are common in rural areas of developing countries. In contrast, more modern cooking stoves (use fuels such as LPG, natural gas and electricity) are common in urban areas of both developing and developed countries. In recent years, biogas cook stoves are also gaining popularity in rural areas of developing countries. However, a stove that is efficient for cooking may not be very efficient for heating, so a household with a clean cooking system may continue to rely on burning polluting fuels in open fireplaces or on traditional heating. Some research institutions, for example, Massachusetts Institute of Technology are currently developing prototype stoves that use stored solar thermal energy for a variety of cooking tasks and space heating, but this is an area that requires further development to bring the efficiencies up and the cost of purchase down. Expanding access to LPG for use in gas space heaters and to biomass pellet-heating stoves can reduce exposure to household air pollution (HAP) from traditional heating stoves and open fires.

Table 4.2: Types of devices used for cooking in households in Matlwang township

Cooking devices used in Matlwang	Percentage of households using types of cooking device
Indoor stove	46
Outside stove	28
Mbaula stove	16
Electric stove	11
Paraffin stove	10
Gas stove	2
Total number of households who participated in the survey: 50	
Source: Own compilation.	

N.B: All households indicated that they use at least two types of stoves.

From the fuel-use survey, six cooking devices are currently used in the township: inside stoves, outside stoves, mbaulas, electric stoves, paraffin stoves and gas stoves. According to the data provided above, an inside stove is the most-preferred cooking device in the township, whilst outside stoves remains the second most-preferred cooking device. There is an 18 % difference between the percentages of households who use inside stoves and outside stoves as cooking devices. This shows an inside stove is the most preferred cooking device in the township. Most households reported that they preferred inside stoves because they are less expensive to buy than the new technology stoves, as it uses wood fuel that is inexpensive compared with other solid fuels. Their preference for inside stove is that it serves two purpose in the households. The households also indicated that they also warm the house while cooking during winter. Wood logs emit a unique warmth which makes the room feel much more pleasant than any other type of fuel. At the same time, the wood-burning stove emits heat long after it has gone out. This makes wood-burning inside stoves unique compared with outside stoves (Bertschi *et al.*, 2003). Black carbon (sooty particles) and methane (CH_4) emitted by inefficient stove combustion are powerful climate-change pollutants. Most households who used outside stoves also stated that they preferred an outside stove because it is less expensive to buy than the new technology stoves, as it uses wood fuel that is inexpensive compared with other solid fuels. Apart from its affordability, the households stated that an outside stove is convenient in summer to avoid too much heat being generated inside the house. Streets and Waldhoff (1999) reported that an outside stove prevents indoor air pollution, unpleasant odours and the danger of a fire. An outside stove keeps the wood outside with no bark, dirt and ash mess to clean up inside the house. People with health problems (such as asthma and heart problems) preferred using outside stoves as they can breathe better when cooking outside the house. Using an outside stove reduces the risk of eye infections as the flames are not directed or shielded (Campbell *et al*., 2002). The inefficient burning of solid fuels on an open fire or in a traditional stove indoors creates a dangerous cocktail of hundreds of pollutants, primarily CO and small particles, but also NO_x, benzene, butadiene, formaldehyde, polyaromatic hydrocarbons and many other health-damaging chemicals.

An mbaula stove is the third most-preferred cooking device in the township. The households reported that an mbaula stove is cheap and saves firewood, as it does not require a lot of firewood when cooking. They also stated that an mbaula does not produce large volumes of smoke emissions in the house as flames are being channelled in one direction when it burns. Campbell *et al*. (2002), reported that a modern mbaula stove can save up to 60 % of firewood compared with the traditional three-stone fire. An mbaula is easy to move if the weather changes and it retains the ashes when moved.

An electric stove is the fifth-preferred cooking device in the township. Members of households who preferred using an electric stove are youths. The households stated that an electric stove is convenient as it has advantages such as safety, easy installation, quick clean up and energy efficiency. They stated that they rely on electric stoves because they are stable and heat evenly using electric elements with thermostats that control the temperature of the oven and stove plates. With an electric cooktop people can place their pots and pans on a completely flat, solid surface. Owing to its flat surface, it is easier to clean as its even surface may be cleaned by wiping it down after people have finished cooking (Kituyi *et al*., 2001a; 2001b). The data above also showed the paraffin stove was the sixth most-preferred cooking device in the township. The households surveyed reported that they preferred using paraffin stoves because of their low fuel consumption, they are cheap, user-friendly and also keep the house warm when they are used for a long period. The affordability of paraffin stoves has been seen as the driving factor of using paraffin as a primary fuel source in the world. Nevertheless, many households use a combination of firewood and paraffin to keep expenses low. Paraffin stoves are also seen as an alternative stand-by technology for urban electricity users during power cuts. Paraffin can be bought in small quantities and thus is affordable for poorer families (Campbell *et al*., 2002). From the data above, gas stoves are the seventh most-preferred cooking device in Matlwang. Of households who preferred gas stoves, 2 % stated that a gas stove is fast and provides more heat when closer to the cooking pot. According to the households, the accurate temperatures and controls of a gas stove allow them to try tricky cooking recipes that might be difficult with another cooking device. Kituyi *et al*. (2001a; 2001b) noted that a gas stove is highly controllable and efficient with instant heat and immediate heat reduction for faster, more economical cooking. Gas is versatile and can be used in a variety of applications from cooking and heating to refrigeration and even lighting.

4.4 Sources of Firewood in Matlwang Township

In Matlwang, firewood is collected from the Kgabaesetswe, Kgapamadi and Tshopane hills (Table 4.3). Of these three collection points, Kgapamadi hill is most preferred by households and vendors for collecting firewood as this hill is the nearest to the households in the township. Vendors preferred collecting firewood from Kgabaesetswe and Tshopane hills.

User preferences for various types of biomass fuels depend largely on local fuel availability, accessibility, and affordability. However, accessibility can significantly limit the availability of firewood in a certain area even where a large tract of natural forest exists in the neighbourhood. Though availability, accessibility and affordability affect the choices of fuel users, most users prefer firewood over inferior biomass fuels (Freudenberger *et al.*, 2004). The community leader in the township also confirmed that the availability of firewood in the Kgapamadi hill area is believed to be one of the main reasons the majority of households preferred collecting firewood for cooking and heating devices. Household decisions are influenced by economic affordability when choosing types of fuel amongst the available options. Economic affordability is a major factor determining local fuel-use patterns (Hahn, 1994a; 1994b). The households and vendors stated that they walk 32 km to collect firewood from the hill. Although households and vendors walk the same distance to collect firewood, there is a time difference of 75 minutes for collecting firewood. Data show that the households spent more time collecting firewood than the vendors who spent less time collecting firewood. Vendors stated that they start collecting firewood around 06:00 in summer and winter whereas most of the households stated that they started to collect firewood between 08:00 and 09:00 in summer and winter. The households stated that collecting firewood requires lot of energy to execute whereas the vendors indicated that they did not collect firewood alone but with their workers and their children who helped them to speed the collection process. Household decisions are influenced by economic affordability when choosing types of fuel amongst the available options. This is a major factor determining local fuel-use patterns. "Affordability may be defined in terms of cash, or time required for self-collection of firewood, or for collection through hired labour. A related factor which affects fuel wood supply is the cost of transportation" (Uhunamure *et al*., 2017).

Table 4.3: Sources of firewood in Matlwang township and time taken to collect the firewood

Place and time involved in collection of firewood			
		Distance travelled (km) and place where firewood collected	
Firewood collectors	**Time spent/collection (minutes)**	**Place where firewood collected**	**Distance travelled (km)**
Households	90 minutes	Kgapamadi hill	32
Vendors	55 minutes	Kgapamadi hill	32
		Kgabaesetswe hill	45
		Tshopame hill	50

Source: Own compilation.

Firewood for daily use is typically acquired within a range of 15 to 20 km from the user, whereas commercial firewood is normally acquired within a range of 80 to 100 km. In limited cases, firewood is transported over long distances. Vendors who collected firewood in Kgabaesetswe and Tshopane hill stated that these two collection points are far. However, they also take 55 minutes to collect firewood regardless of the walking distance to the collection points. There are currently three active vendors selling firewood in Matlwang. All three vendors stated that they are also residents of the town. They reported that they sell firewood only in the township using their own donkey carts. These vendors also indicated that they sell firewood at different prices per donkey cart load: the lowest price is ZAR 120, the medium price is ZAR 150 and the highest price is ZAR 200. They also stated that collecting firewood depend on orders from customers in the township. From the survey, the majority of households recommend vendor's prices compared with other places near the township. They compared prices of vendors with supermarkets and garages where they usually sell firewood in bags and cords. Historically, the main use of donkeys has been for transport. For many years, donkeys provided only the alternative to head-loading, back-packing and walking (Fernando, 1997). This is a cheap and easy way of transporting goods, especially over rough and hilly terrain. As long as the load is correctly placed on the back of the animal and a proper loading system is used, a donkey can easily carry between 27 % and 40 % of its own body mass. Prices of firewood vary considerably with the distance from wood lots and quality of the wood (Erakhrumen, 2010). Buying and burning firewood that was cut only a short distance from its final destination reduces the price of firewood.

Matlwang has diverse plant species, trees, shrubs, grasses and lianas. Table 4.4 contains the scientific names, common names and local names of the preferred trees species for firewood in the township (van Wyk, 2000; Hahn, 1994a; 1994b). The households preferred only three types of tree species for firewood (Table 4.4). Of the 50 households interviewed, 40 of them preferred *Mooka* species for firewood, while four households preferred *Moumo* species.

Table 4.4: Preferred tree species for firewood by households of Matlwang

Tree species for firewood			Percentage of households who preferred a specific tree species for firewood	Number of households who preferred a specific tree species for firewood
Scientific Name	**Common name**	**Local name**		
Senegalia ataxacantha	Flame thorn	Mooka	80	40
Ficus sur	Broom cluster fig	Moumo	8	4
Aphloia theiformis	Mountain peach	Mmilo	2	1
No preference	-	-	10	5
Total number of households who participated in the survey: 50				

Source: Own compilation.

Only one household claimed to prefer the *Mmilo* species for firewood. According to the data provided in Table 4.4, 80 % of households preferred M*ooka* species because it produces flames that last longer when it burns. Tree species that do not essentially serve as a food source, but burn well and smoke less are exploited for firewood. Even some species which are known to produce gradual and good flames are preferred for firewood (Mucina & Rutherford, 2006). They also stated that the *Mooka* species is accessible and available in the township. From observations during the survey, this tree species is also available in streets in township. Most households in the township reported that the species reproduces simultaneously and can survive very dry conditions. The *Vachellia ataxacantha* species grows naturally from seeds that germinate easily during the rainy season. Its preferred habitat is deep, dry sandy soils (Brown *et al*., 1996). Acocks (1975) defined *Vachellia ataxacantha* species as the indigenous tree species which is not listed as being a threatened species as it can also be used for chemical products, forage, domestic uses, environmental management, fibre, food, drink, and wood. Hahn (1994a; 1994b) described the *Vachellia ataxacantha* species as a species with a long history of medicinal use in the treatment of diarrhoea, urinary tract infections, throat inflammation, gastritis, tuberculosis and headaches.

The leaf decoction is used orally in febrile convulsions. Its bark is used against tooth decay and, in the case of bronchitis and coughs, by inhalation. In Nigeria, pods and seeds of *Vachellia ataxacantha* are also used against dysentery (Freudenberger *et al.*, 2004). Its roots are used in Kenya in the treatment of joint and back pain. Of households who preferred the *Moumo* species for firewood, 8 % stated that firewood from the *Moumo* species is quick to ignite and burns readily. Several studies indicated that the wood from many tree species requires to be split into small sections and given plenty of time to dry to light easily and also to produce a good flame. The households also stated that the tree species is also accessible and it can be collected not far from the households. They claimed to walk < 4 km to collect the species for firewood. According to Mucina and Rutherford (2006), *Ficus sur* is also defined as an indigenous tree species and is a species which is not harmful to human beings. This species is also used to treat different diseases such as diarrhoea and anaemia as well as sexually transmitted diseases (Hahn, 1994a; 1994b). Of households who preferred *Mmilo* species for firewood, 2 % stated that this tree species is easy to cut. They reported that it does not take much time to get the fire ready for cooking and heating the house. *Aphloia theiformis* is a light and soft species which is not much used commercially. This tree species is found mostly in forests or grassy woodlands and occurs at higher densities in well-watered temperate uplands. Brown *et al.* (1996) also identified *Aphloia theiformis* as an indigenous tree species which is not harmful to human beings.

4.5 Firewood Usage in Matlwang Township

In Matlwang, both men and women use firewood for cooking and heating. Of the 50 households that participated in the survey, 36 women indicated that they used firewood and this can be compared to 11 children and only 2 men who said the same. The above data show that mothers tend to use firewood more compared with other members of their households. Gender roles in the household include who does the cooking and other domestic work, who works outside the home, who makes decisions about buying fuels and appliances, and other differences in behaviours between men and women are major determinants of relative health risks (WHO, 2015). The gender dynamics of household energy use vary from place to place but they tend to be driven both by deep-seated cultural norms and economic factors. A variety of case studies have found that women are effective energy entrepreneurs, employees and sales agents (Khan, 2001). In many countries, including Kenya, women have less access to inherited land, education, employment, loans and money than men. In places where access is unequal, millions of women and their families have trouble finding enough food and are unable to pay for farming inputs or their children's school fees.

Table 4.5: Firewood usage in Matlwang township

Household member who uses firewood in Matlwang	Percentage of households who uses firewood	Number of respondents who uses firewood
Mother	60	30
Children	22	11
Grandmother	12	6
Father	4	2
Grandfather	2	1
Total number of households who participated in the survey: 50		

Source: Own compilation.

The lowest percentage (2 %) of people who used firewood in the households are grandfathers. Of mothers who used firewood, 60 % stated that they use firewood to enable domestic activities in the households such as cooking, boiling water and warming the house. They also reported that it is their duty to carry out some of these activities as their tradition binds them to cook for their households, especially their husbands. The majority of mothers asserted that food cooked with firewood tastes good and smells nice. Firewood connoisseurs will assess a firewood's aroma. Some people attach tradition to various smells that different woods have when burned. According to some, a pleasant aroma is best achieved through burning fruit woods. Meat smokers have utilised fruit woods through history as a major component in the taste of their meats (Katsouyanni, 2003). Fruit woods such as oak, apple, cherry, hickory, and pecan are Oklahoma woods that have an aroma that resembles their fruit. The selection of fuel for cooking is also cultural. According to Baldwin *et al.* (2006), "culture encompasses religion, food, what to wear, language, marriage, music, beliefs, what is right or wrong, how to sit at the table, how to greet visitors, how to behave with loved ones and many other things".

In some cultures, the smoke from domestic fuel use is believed to have a benefit in repelling mosquitoes which carry diseases such as malaria. However, while the burning of particular aromatic plants may have some efficacy in repelling mosquitoes, the WHO (2008) found that the presence of cooking smoke has no effect on the indoor abundance of African malaria vectors. In any case, under normal conditions of domestic fuel use, most cooking is done outside the peak biting times for malaria vectors. Firewood taken from fruit and nut trees often commands a higher market price than woods with higher calorific values.

It is clear that there is a clear division of labour among men and women in the township with women using firewood more and being responsible for the bulk of the domestic activities. This is also evident in South Asia where women play a significant and dominant role within the household cooking sector (Rehfuess, 2006). Generally, "women do most of the cooking and are, therefore, disproportionately affected by household air pollution (HAP) caused by the inefficient burning of solid biomass cooking fuels. They are also required to spend a significant amount of time and effort collecting the traditionally used biomass fuels which is a physically draining task that can take up to 20 or more hours per week" (Rehfuess, 2006). Most women tend to cook inside these houses even though they have no windows and there is insufficient air circulation. This eventually leads to several health problems mostly for the women and children who are most exposed. Erakhrumen *et al*. (2010) stated that these women end up having "red eyes" which sometimes also lead to discrimination against them as women with red eyes are thought to be wicked people who practise witchcraft in the communities The Grandfather who uses firewood stated he stays alone. Because of his age he cannot read nor use other sources of energy like electricity. He reported that even though his house is electrified, he cannot use electricity because it is too complicated for him. The grandfather also stated that he sometimes sends his neighbour's daughter to collect firewood and pays her for he is too old and can no longer walk long distances.

It is also worth noting that the use of firewood among the women and children has led to several injuries (especially burns mostly amongst the young girls). This happens when young girls are left cooking food for their brothers during the day when their mothers have to walk a long way in search of more firewood and water (Katsouyanni, 2003).

4.6 Burning Patterns and Mass of Firewood Consumed in Summer in Matlwang Township Households

There are three burning events of firewood per day in the township. The households in the township burn firewood in the morning, afternoon and in the evening, with 80 % of households burning firewood in the morning, 50 % of the households burning firewood in the afternoon, and 60 % of the households burning firewood in the evening (Table 4.6). In the morning, 48 % of households start burning firewood at 04:00 and end burning firewood at 07:00.

Table 4.6: Burning patterns and mass of firewood consumed per day in summer in the households of Matlwang township

Burning event	Burning time		Percentage of households burning firewood	End-use functions	Total mass of firewood consumed by households per day (kg)	Average mass of firewood consumed by households per burning event per day (kg)
	Start burning time	End burning time				
Morning	04:00, 05:00, 07:00 & 09:00	07:00, 08:00, 09:00 & 10:00	80 %	Boiling water for bathing, cooking breakfast & cooking food for business	182	9.1
Afternoon	12:00, 13:00 & 15:00	15:00 & 16:00	50 %	Boiling water for bathing, cooking & warming food for lunch	92	4.7
Evening	18:00 & 21:00	19:00, 20:00, 21:00 & 22:00	60 %	Cooking food for supper, boiling water for bathing & warming the house	125	6.26
Total mass of firewood consumed by 50 households per day (kg): 399				**Total average mass of firewood consumed by 50 households per day (kg): 20**		
Total number of households that participated in the survey: 50						

Source: Own compilation.

Between 05:00 and 08:00, 12 % of households start burning firewood, 10 % of households start burning firewood at 07:00 and end burning firewood at 09:00 whereas 10 % of households start burning firewood at 09:00 and end burning firewood at 10:00. In the afternoon 26 % of households start burning firewood at 12:00 and end burning firewood at 15:00, 16 % of households start burning firewood in the afternoon at13:00 and end burning firewood at 16:00, and 8 % of households start burning firewood at 15:00 and end burning firewood at 16:00.

In the evening, 23 % of households start burning firewood at 18:00 and end burning at 19:00; 7 % of households start burning firewood at 18:00 and end burning firewood at 20:00; 13 % of households start burning firewood in the evening at 18:00 and end burning firewood at 21:00, and 17 % of households start burning firewood in the evening at 21:00 and end burning firewood at 22:00.

There is a variation of burning time difference between the mornings, afternoon and evening events. The morning burning events in households are longer and last 6 hours whereas the evening burning events last 4 hours. The afternoon burning events are shortest and last only 2 hours. There is an 8-hour time difference from the start of burning firewood in the morning until the fire is lit again in the afternoon. The time difference between starting to burn firewood in the afternoon and lighting the evening fire is 6 h. The time difference between the time of ending burning the fire in the morning and ending the fire in the afternoon is ~ 6 h. The time difference to end burning firewood in the afternoon and evening is also ~ 7 h. Of the three daily household burning events, most firewood is consumed in the morning, followed by the evening burning. Midday burning uses the least firewood.

Yevich and Logan (2003), stated that wood goes through different stages when it burns. Heating efficiency of firewood depends on how that wood progresses through those stages. Energy is expended in each of these stages. In the **first stage**, wood is heated to a point where the moisture within the wood cells can evaporate. After the wood has dried, it then undergoes a chemical breakdown to charcoal, volatile gases and volatile liquids. The **second stage** is indicated by the obvious visual sign of actual flames which are volatile gases and volatile liquids. Finally, the **third stage** occurs when the charcoal burns and can be seen when the embers glow. The heat is then radiated from the burning charcoal during this third stage. Different species of wood burn and expend energy differently throughout these three stages. In summer, all 50 households together consume 399 kg of firewood daily. The heating value of wood depends upon the density of that wood. In general, the heavier or denser woods contain higher heating values (Campbell *et al*., 2002). The variation in density between different species can be quite large. Lighter woods (such as cottonwood and willow) produce roughly the same heat value per unit mass as heavier woods (such as oak). Wood that is less dense produces less heat per unit volume. This means that a greater volume of cottonwood is needed than oak to produce the same amount of heat. Some species of wood catch alight more easily than others and, when burned, they give off more smoke or more sparks than others. Therefore, in summer, a total mass of 399 kg of wood is consumed daily across all households in Matlwang township.

4.7 Burning Patterns and Mass of Firewood Consumed in Winter in Matlwang Township Households

As in the summer season, there are three daily **winter** firewood burning events in the township (Table 4.7). Households in the township also burn firewood in the morning, afternoon and in the evening. Of households burning firewood, 88 % burn a fire in the morning, 70 % of households burn firewood in the afternoon, and 94 % of households burn firewood in the evening.

In the **morning**, from the above data, 36 % of households start burning firewood at 04:00 and end burning at 07:00; 22 % start burning firewood at 05:00 and end burning at 08:00; and 22 % of households start burning firewood at 07:00 and end burning at 09:00. Only 8 % of households start burning firewood at 09:00 and end burning at 10:00.

In the **afternoon,** 20 %, of households start burning firewood at 12:00 and end burning at 14:00; 32 % of households start burning firewood in the afternoon at 13:00 and end burning at 16:00, whilst 18 % of households start burning firewood at 15:00 and end burning at 16:00.

In the **evening,** 34 % of households start burning firewood at 18:00 and end burning at 20:00; 34 % of households start burning firewood in the evening at 19:00 and end burning at 00:00, and 26 % of households start burning firewood in the evening at 20:00 and end burning at 00:00.

Of the three burning events in the households, more firewood consumption takes place in the evening than in the morning and afternoon. There is a variation of burning time difference between the morning, afternoon and evening events. The morning and evening burning events in the households are longer and last for 6 hours, whereas the afternoon burning events are shorter and last for 4 hours. The time difference to start burning firewood in the morning and afternoon is 8 hours, whilst the time difference to start burning firewood in the afternoon and evening is 6 hours. The time difference to end burning in the morning and afternoon is 6 hours, whereas the time difference to end burning in the afternoon and evening is also 8 hours. More firewood is consumed in the evening because the households burn more firewood for space heating. For space heating, some households indicated that they used a firewood stove, whereas the majority of households used an mbaula stove. The process of burning firewood in an mbaula stove for space heating was confirmed in this study during the winter season in the evening, although the end burning time was not confirmed because the whole process happens in the evening. The households reported that the firewood ashes in an mbaula stove can give off heat for 5 to 6 hours.

The households explained the heating process as follows: they stated that in the **evening**, they placed the mbaula stoves outside their houses and burned firewood in the mbaulas. After the firewood has burned down and produced ashes, they bring their mbaula stoves inside their houses. They also stated that this process is not risky as they put their mbaula stoves on top of a piece of galvanised iron to avoid hot ashes falling onto the floor. Depending on the quantity of firewood burned in their mbaulas, they use firewood ash to heat the house in the evening. The use of firewood stoves for space heating in the evening was not confirmed as this was stated only by the households. The households reported that their firewood stoves produce enough heat to heat their houses.

Table 4.7: Burning patterns and mass of firewood consumed per day in winter in the households of Matlwang township

Burning event	Burning time		Percentage of households burning firewood	End-use functions	Total mass of firewood consumed by households per day (kg)	Average mass of firewood consumed by households per burning event per day (kg)
	Start burning time	End burning time				
Morning	04:00, 05:00, 07:00 & 09:00	07:00, 08:00, 09:00 & 10:00	88 %	Boiling water for bathing, cooking breakfast & cooking food for business	238	12
Afternoon	12:00, 13:00, & 15:00	14:00, 15:00 & 16:00	70 %	Boiling water for bathing, cooking food for lunch & warming food for lunch	220	11
Evening	18:00, 19:00 & 20:00	22:00 & 00:00	94 %	Cooking food for supper, boiling water for bathing & warming house	244	12.20
Total mass of firewood consumed by 50 households per day (kg): 702				**Total average mass of firewood consumed by 50 households per day (kg): 36**		
Total number of households participated in the survey: 50						
Source: Own compilation.						

Various stove designs heat the space in different ways (Figure 4.1). Depending on its design, a wood stove may deliver most of its heat by direct radiation via the convection flow of warmed air or both. Radiation is the direct transfer of heat from the hot stove surfaces to walls, furniture and people that are in direct line of sight from the stove (Andreae *et al*., 1996). Most wood-burning appliances function primarily as space heaters. A space heater is intended to heat a space directly unlike a central heating furnace or boiler which supplies heat to the house through a system of ducts or pipes (Bertschi *et al*., 2003). Kituyi *et al.* (2001a; 2001b) stated that selecting a stove with the correct heat output range can be tricky because the stove's appearance does not always reflect its performance. If the stove's output is too large for the space to be heated, it will be turned down low much of the time, producing a smoky fire. An undersized stove meanwhile may deteriorate because of constant over-firing (over-heating). A mass of 702 kg of firewood is consumed daily in winter in the township.

Source: Own photographs

Figure 4.1 A picture showing the types of stoves used for space heating in Matlwang

4.8 Quantification and Estimation of Emissions from Domestic Fuel Use in Matlwang Township Households

Hanging scales and questionnaires were distributed to twenty randomly selected households in Matlwang township to weigh the amount of fuel wood they were using. Participating households were asked to weigh the wood they used in the morning, afternoon and evening on a daily basis. In summer data were collected from 05 February to 16 February 2017. In winter data were collected from 28 May to 08 June 2017. The collected data were analysed to determine the consumption quantities and patterns and emissions were calculated/estimated using emission factors presented in Table 3.1. The emissions of CO_2, CO, NO and CH_4 were calculated for wood, using these emission factors. The mass of firewood used for each household per month was calculated and then multiplied by the emission factor for the specific gas pollutant to obtain the emission in grams.

Table 4.8 shows the average per caput wood consumption in Matlwang township for summer, winter and annually. Findings indicated that firewood consumption in summer is highest in the morning, and lowest in the afternoon, and similar during the different times of the day in winter except for night-time when wood are burnt for longer period of time. In this study, winters were considered to last for 4 months and summers for 8 months. Higher firewood consumption of 7.8 kg (±2.9) per caput was recorded in the winter season compared with 4.8 kg (±2.4) per caput in the summer season. The fuel wood per caput consumption for Matlwang was higher compared with what was recorded elsewhere. For example, Mulaudzi (2006) reported estimates as low of 0.05 kg per caput per day in **Lesotho** to upwards of 3.0 kg per caput per day in the eastern highland countries of Kenya, Tanzania, Uganda and Zambia throughout the year.

Table 4.8: Average wood consumption per caput in Matlwang township

	Summer (kg)	Winter (kg)	Annual (kg)
Morning (kg)	9.1 ± 2.6	11.9 ± 3.6	10.5 ± 3.4
Afternoon (kg)	4.9 ± 0.7	11.1 ± 3.1	8.0 ± 3.9
Evening (kg)	6.3 ± 0.9	12.2 ± 4.3	9.2 ± 4.3
Total day^{-1} (kg)	20.2 ± 2.8	35.2 ± 7.1	27.7 ± 9.2
Total number of people in the household	5.1 ± 2.0	5.1 ± 2.0	5.1 ± 2.0
Consumption of wood person^{-1}.day^{-1} (kg)	4.8 ± 2.4	7.8 ± 2.9	6.3 ± 3.0
Consumption of wood person^{-1}.month^{-1} (kg)	144.4 ± 73.1	233.9 ± 85.9	189.1 ± 90.8
Consumption of wood person^{-1}.year^{-1} (kg)	1,155.0 ± 585.0	935.4 ± 343.5	1,045.2 ± 486.4
Note: *The number of people in the township was estimated to be 2,500*.			
Source: Own compilation.			

Table 4.9 and Table 4.10 show the wood consumption and resultant CO_2, CO, NO and CH_4 emissions in Matlwang township for summer and winter months, respectively. Findings of the study show that the summer monthly per caput emission for CO_2 is 0.055 t per summer month and the annual per caput consumption is 0.44 t. The township emits about 138.06 t of CO_2 per month in summer and 1104.46 t of CO_2 per year.

Table 4.9: Summer wood consumption and resultant emissions in Matlwang township

	Average consumption of wood in summer (kg) per person	Standard Deviation (kg)	Average consumption of wood in summer (kg) for township	Average consumption of wood in summer (tonnes) for township
Consumption of wood person^{-1}.day^{-1} (kg)	4.8	± 2.4	–	–
Consumption of wood person^{-1}.month^{-1} (kg)	144.4	± 73.1	–	–
Consumption of wood person^{-1}.year^{-1} (kg)	1155.0	± 585.0	–	–
CO_2 (g.C.month^{-1})	55,222.98	± 27,968.32	138,057,455.36	138.06
CO (g.C.month^{-1})	5,276.86	± 2,672.53	13,192,156.85	13.19
NO (g.N.month^{-1})	63.81	± 32.32	159,533.06	0.16
CH_4 (g.C.month^{-1})	184.08	± 93.23	460,191.52	0.46
CO_2 (g.C.year^{-1})	441,783.86	± 223,746.58	1,104,459,642.86	1,104.46
CO (g.C.year^{-1})	42,214.90	± 21,380.23	105,537,254.76	105.54
NO (g.N.year^{-1})	510.51	± 258.55	1276,264.48	1.28
CH_4 (g.C.year^{-1})	1,472.61	± 745.82	3681,532.14	3.68

Note: *The number of people in the township was estimated to be 2,500*.

Source: Own compilation.

The findings of the survey show that the per caput CO_2 emissions of 0.089 t were higher than the 0.055 t per summer months and the annual CO_2 projection of 1104.46 t per annum was higher than the annual summer projection.

Table 4.10: Winter wood consumption and resultant emissions in Matlwang township

	Average consumption of wood in winter (kg) per person	Standard Deviation (kg)	Average consumption of wood in winter (kg) for township	Average consumption of wood in winter (tonnes) for township
Consumption of wood person^{-1}.day^{-1} (kg)	7.8	± 2.9	–	–
Consumption of wood person^{-1}.month^{-1} (kg)	233.9	± 85.9	–	–
Consumption of wood person^{-1}.year^{-1} (kg)	935.4	± 343.5	–	–
CO_2 (g.C.month^{-1})	89,451.27	± 32,851.31	223,628,169.64	223.63
CO (g.C.month^{-1})	8,547.57	± 3,139.13	21,368,913.99	21.37
NO (g.N.month^{-1})	103.37	± 37.96	258,414.77	0.26
CH_4 (g.C.month^{-1})	298.17	± 109.50	745,427.23	0.75
CO_2 (g.C.year^{-1})	357,805.07	± 131,405.25	894,512,678.57	894.51
CO (g.C.year^{-1})	34,190.26	± 12,556.50	85,475,655.95	85.48
NO (g.N.year^{-1})	413.46	± 151.85	1,033,659.10	1.03
CH_4 (g.C.year^{-1})	1,192.68	± 438.02	2,981,708.93	2.98
Note: *The number of people in the township was estimated to be 2,500.*				
Source: Own compilation.				

Considering that each household had an average of five people, the findings indicate the households utilise approximately 20.2 (±2.8) to 35.2 (±7.1) kg.wood.household^{-1}.day^{-1} or 4.8 (±2.4) to 7.8 (±2.9) kg.wood.person^{-1}.day^{-1} in summer and winter, respectively. The resulting emissions for the township of CO_2, CO, NO and CH_4 are 894 (±328), 85 (±31), 1 (±0.3) and 3 (±1) tonnes.annum^{-1}, respectively.

The firewood consumption per caput for Matlwang was higher compared with what was recorded elsewhere. For example, Mulaudzi (2006) reported estimates as low as 0.05 kg person^{-1}.day^{-1} (that is, 50 g person^{-1}.day^{-1}) in Lesotho to upwards of 3.0 kg person^{-1}.day^{-1} in the eastern highland countries of Kenya, Tanzania, Uganda and Zambia throughout the year.

According to Yevich and Logan (2003), daily wood consumptions as low as 0.1 kg person^{-1}.day^{-1} are common in Asian countries such as Afghanistan, Iraq and Pakistan. This is attributed to fuel wood deficiency in this region and the vast endowment of these countries with open mixed forest grassland and shrub vegetation zones with only a small wood supply available to the large rural population, hence their very low fuel wood consumption (Yevich & Logan, 2003). In these areas, agricultural residues are often used as a substitute (Yevich & Logan, 2003). Elsewhere, daily fuel wood consumptions of ~ 3.0 kg person^{-1}.day^{-1} are common, with Paraguay being an example (Mulaudzi, 2006).

The findings of the study showed that the summer and winter monthly per caput emission for CO_2 is 0.055 tonnes per summer month and 0.089 tonnes per winter month. The township emits about 138.06 tonnes of CO_2 per month in summer and 223.63 tonnes of CO_2 in the winter season. The findings indicate in summer the households utilise ~ 20.2 (± 2.8) kg.wood.household.day^{-1} and, in winter, ~ 35.2 (± 7.1) kg.wood.household.day^{-1} or ~ 4.8 (± 2.4) kg.wood.person.day^{-1} in summer and ~ 7.8 (± 2.9) kg.wood.person.day^{-1} in winter, respectively. The resulting emissions for the township of CO_2, CO, NO and CH_4 are 894 (± 328), 85 (± 31), 1 (± 0.3) and 3 (± 1) tonnes.annum^{-1}, respectively. According to Mulaudzi (2006), South Africa emits 9.12 Mt C.yr^{-1} of CO_2, 0.89 Mt C.yr^{-1} of CO, 10.77 Mt N yr^{-1} of NO, and 30.25 Mt C yr^{-1} of CH_4. Based on these figures the township contributes approximately 0.00889 % of the country's CO_2 emissions which is far too little considering that the township contains about 0.044 % of the South Africa's population.

Using the winter months' per caput CO_2 emissions, the annual per caput CO_2 emission in the township will be 1,068 tonnes of CO_2 per annum. This can be compared with gross emissions per person for South Africa, which were estimated to be 9.8 tonnes of CO_2 equivalent per person in 2015; 9.93 tonnes of CO_2 equivalent per person in 2000 and 10.82 tonnes of CO_2 equivalent per person in 2010 (Cayley & Mwiti, 2019). This clearly demonstrates that the per caput CO_2 emissions reported for the township are way below the national per caput CO_2 emissions.

In many regions of Africa a firewood crisis, due mainly to population increases, has been noticed. Firewood's increasing scarcity is a subject of major concern in Africa. High population growth rates and increasing household fuel demands are associated with rapid increases in trace gas emissions (Mulaudzi, 2006).

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The consumption rate of firewood in the township was analysed to quantify the total amount of firewood burnt per fire per household during summer and winter, per month per household as well as per annum per household.

CHAPTER 5:
CONCLUSIONS AND RECOMMENDATIONS

This chapter provides a summary of the findings and the conclusions made based on the objectives of the study. It also provides recommendations based on the limitations of the study.

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5.1 Conclusions

This study revealed the common and most preferred fuels used in the township of Matlwang. The study also documented the most common cooking devices, emissions produced by the fuel types used, the importance of firewood, sources of firewood, tree species preferred for firewood and the current consumption rate of firewood in the township of Matlwang. The study shows that firewood is by far the cooking fuel choice for the majority of households in Matlwang, with 86 % of households use firewood for cooking and heating. The households use firewood for boiling water, cooking and heating the space. There are three burning patterns in the township. The households burn firewood in the morning, afternoon and evening. However, the consumption rate (702 kg) of firewood in the township in winter is higher than the consumption rate of firewood in summer (399 kg). This is due to a large amount of firewood burnt in winter in order to heat the living space. Marufu *et al*. (1997) showed that areas that burn large quantities of firewood have a higher proportion of CO_2 and CO. The results indicate the households utilise approximately 20 (±2.8) $kg.wood.household^{-1}.day^{-1}$ (in summer) and 35 (± 7.1) $kg.wood.household^{-1}.day^{-1}$ (in winter) or 4.8 (± 2.4) $kg.wood.person^{-1}.day^{-1}$ (in summer) and 7.8 (± 2.9) $kg.wood.person^{-1}.day^{-1}$ (in winter), respectively. The resulting emissions for the township of CO_2, CO, NO and CH_4 are 894 (± 328), 85 (± 31), 1 (± 0.3) and 3 (± 1) $t.annum^{-1}$.

Although the majority of households in the township preferred firewood as a source of energy, some households in the township preferred to use other types of fuels such as electricity, gas, cow dung and paraffin fuel. Of the township households, 72 % preferred using electricity for cooking and heating. Most households using electricity in the township stated that they use electricity for lighting, although other households use it for cooking and space heating. Most households reported that electricity is expensive, and they cannot afford to use it for cooking, boiling water and lighting on a daily basis. Other types of fuels (such as cow dung, gas and paraffin) are used frequently by the households to replace wood and electricity. Of households who use cow dung, 28 % asserted that cow dung is cheap, available and accessible in the township.

From the survey, the township has a large unemployed population where poverty is rife and households therefore have to rely on less convenient and often harmful fuels. The majority of households in the township own cattle, which makes it easy for households to replace firewood and electricity with cow dung for cooking and heating the house. These households reported that cow dung produces a large amount of ash which warms their house in the evening during winter. Yevich and Logan (2003) stated that dung is typically a fuel associated with economic or fuel poverty. Paraffin and gas fuels are usually utilised during summer and when the ambient temperature is fairly warm. Of households who preferred using paraffin, 10 % stated that paraffin is inexpensive and also sold in the township. Paraffin is the most common complimentary fuel within completely un-electrified settlements as it is used not only for cooking but also for lighting by means of paraffin lanterns (Gupta *et al*., 2001). The 2 % of households who preferred using gas stated that gas is fast and clean. Gas is well suited for use indoors because it is inherently clean and burns without smoke or residual particulate matter. It has a lower carbon content than gasoline, diesel, kerosene and ethanol (Balmer, 2007). The results of this study show that unemployment rate, poverty, culture, age, lack of access to electricity and availability of firewood are cogent reasons the households in Matlwang continue to use firewood as a source of energy.

5.2 Recommendations

This study seeks to recommend a massive output of information that would address the lack of knowledge on the wise use of trees for environmental sustainability.

- Whereas firewood is mostly harvested and used by women, most of the decisions on firewood are taken by men. Consequently, it may be useful that women should be empowered on sustainable firewood use.

- It is important to encourage and popularise a fuel switch from using more firewood to other domestic sources of energy such as LPG, Biogas, and Solar. The use of LPG or other domestic sources of energy relieves women from much of the most arduous tasks involved in cooking for their families and permits them to lead a relatively comfortable and healthy life.

- There should be a creation of well-paying job opportunities for the residents so that they can afford to buy modern fuels such as electricity.

- Commercial regulation of firewood harvesting should be implemented to negotiate a volume to be harvested per seller in a specified time.

- Future studies looking into the quantification of particulate matter at household level as a result of burning firewood for domestic purposes are also recommended for the township. This will help understand the levels of exposure to the community members and also come up with ways to reduce exposure and avoid future human health impacts.

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Reasons for using firewood by households in the township were outlined in this chapter as well as the recommendations for additional research.

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APPENDIX

Appendix A: Questionnaire used to collect data

Quantifying the use of firewood as a source of energy in North West Province: A case study for Matlwang	
The total number of households to be interviewed in the study	50
NB. Please use a tick (✓) in the box next to the appropriate answer	✓
How many males that lives in your household?	
1. One	
2. Two	
3. Three	
4. Four	
5. Five	
6. Six	
7. Seven	
8. Eight	
9. Nine	
10. Ten	
How many females that lives in your household?	
1. One	
2. Two	
3. Three	
4. Four	
5. Five	
6. Six	
7. Seven	
8. Eight	
9. Nine	
10. Ten	
What is the average income of the household?	
1. 0-400	
2. 400-800	
3. 800-2000	
4. 2000-5000	
5. 5000-8000	
6. 8000 and above	
How much money do you spend on food per month?	
1. 0-400	
2. 400-800	
3. 800-2000	
4. 2000-5000	
What type of fuel do you use in your household?	
1. Wood	
2. Electricity	
3. Cow dung	

4. Gas	
5. Paraffin	
What is the cooking device you use in your household?	
1. Electric stove	
2. Inside fire	
3. Outside fire	
4. Paraffin stove	
5. Gas stove	
6. Mbaula	
Who uses firewood in your household?	
1. Age between **6** and **12**	
2. Age between **12** and **22**	
3. Age between **22** and **30**	
4. Age between **31** and **35**	
5. Age between **36** and **40**	
6. Age between **41** and **49**	
7. Age of **50** and above	
How many times per day do you make fire in your household?	
1. One	
2. Two	
3. Three	
4. Four	
5. Five	
6. Six	
7. Seven	
8. Eight	
9. Nine	
10. Ten	
Who does the cooking in your household?	
1. Children	
2. Mother	
3. Father	
4. Grand mother	
5. Grand father	
Which tree species do you prefer for firewood?	
1. Sweet thorn (Mooka)	
2. Flame thorn (Mogotela)	
3. Pride-of-De kaap (Mogatuole)	
4. Mountain peach (Mmilo)	
5. Broom cluster (Moumo)	
What is the reason behind the choice of specific trees species for firewood?	
1. Accessibility of tree species	
2. The tree species is quick to catch fire	
3. The tree species produce flames that last longer	
How often do you collect fire wood in summer?	
1. Everyday	
2. Once per week	

3. Twice per week	
4. Thrice per week	
5. Four times per week	
6. Five times per week	
How often do you collect firewood in winter?	
1. Everyday	
2. Once per week	
3. Twice per week	
4. Thrice per week	
5. Four times per week	
6. Five times per week	
Where do you collect firewood?	
7. Kgapamadi hill	
8. Kgabaesetswe hill	
9. Tshopame hill	
Where do you buy firewood?	
1. Vendors	
2. Filling station/Garages	
3. Super markets	
What is the reason for using firewood in your household?	
1. Poverty	
2. It is user friendly	
3. It is cheaper	
4. Any other reason	
At what time do you start burning firewood in the morning?	
1. 4:00am	
2. 4:30am	
3. 5:00am	
4. 5:30am	
5. 6:00am	
6. 6:30am	
7. 7:00am	
8. 7:30am	
9. 8:00am	
10. 8:30am	
11. 9:00am	
12. 9:30am	
13. 10:00am	
14. 10:30am	
15. 11:00am	
16. 11:30am	
At what time do you stop burning firewood in the morning?	
1. 4:30am	
2. 5:00am	
3. 5:30am	
4. 6:00am	
5. 6:30am	
6. 7:00am	

7. 7:30am	
8. 8:00am	
9. 8:30am	
10. 9:00am	
11. 9:30am	
12. 10:00am	
13. 10:30am	
14. 11:00am	
15. 11:30am	
At what time do you start burning firewood in the afternoon?	
1. 12:00pm	
2. 12:30pm	
3. 13:00pm	
4. 13:30pm	
5. 14:00pm	
6. 14:30pm	
7. 15:00pm	
8. 15:30pm	
9. 16:00pm	
10. 16:30pm	
11. 17:00pm	
12. 17:30pm	
At what time do you stop burning firewood in the afternoon?	
1. 12:30pm	
2. 13:00pm	
3. 13:30pm	
4. 14:00pm	
5. 14:30pm	
6. 15:00pm	
7. 15:30pm	
8. 16:00pm	
9. 16:30pm	
10. 17:00pm	
11. 17:30pm	
At what time do you start burning firewood in the evening?	
1. 18:00pm	
2. 18:30pm	
3. 19:00pm	
4. 19:30pm	
5. 20:00pm	
6. 20:30pm	
7. 21:00pm	
8. 21:30pm	
9. 22:00pm	
10. 22:30pm	
11. 23:00pm	
12. 23:30pm	
13. 00:00pm	

At what time do you stop burning fire wood in the evening?	
1. 18:30pm	
2. 19:00pm	
3. 19:30pm	
4. 20:00pm	
5. 20:30pm	
6. 21:00pm	
7. 21:30pm	
8. 22:00pm	
9. 22:30pm	
10. 23:00pm	
11. 23:30pm	
12. 00:00pm	
How much load of firewood do you afford?	
1. R120	
2. R150	
3. R200	
How long does a load of firewood last?	
1. One week	
2. Two weeks	
3. Three weeks	
4. Four weeks	
5. Five weeks	
6. Six weeks	
7. Seven weeks	
8. Eight weeks	
9. Nine weeks	
10. Ten weeks	
The distance residents and vendors walk to collect firewood?	
1. 45 minutes	
2. 1 hour	
3. 1h30	
4. 2 hours	
5. 2h30	
6. 3 hours	
How many times do residents and vendors collect firewood per day?	
1. Once	
2. Twice	
3. Three times	
4. Four times	
How many times do residents and vendors collect firewood per week?	
1. Once	
2. Twice	
3. Three times	
4. Four times	