Exploring the efficacy of solar photovoltaic application as an alternative energy source for rural households in Atok, Limpopo

A Dissertation Submitted to the Faculty of Science, University of Johannesburg, in fulfilment of requirements for the award of Master of Philosophy in Energy Studies

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Dedications and Acknowledgements

I dedicate this work to my parents, Motale Monica Moshopiadi and Serobane Esrom Hlabirwa Peta. My late father Mr Hlabirwa always said "*Mosadi ke go nyala monna yoo a ka se tsogileng a mo tlogetše*; *e le go yona thuto*", which means a lady must marry a man that will never leave her, that being education.

God made it all possible, through all trials and tribulations, thanks to Him.

To my supportive family and friends, I deeply appreciate your efforts to ensure that not only do I complete my dissertation but that it is a rigorous one. Particularly, my mother Motale M. Peta for words of encouragement, my brother Mamakoba G. Peta for leading from the forefront educationally and setting the bar high for us, and my siblings for their great support throughout. Gratitude goes to Faith M. Mamphoka for reviewing my work and supporting me throughout. Many thanks to Norman Boshego for encouraging me to start this journey, supporting me through it all right to the end and his input to improve the quality of this work. To my cooperative lovely daughters (Kgwerano and Kamano), who have inspired me word by word, chapter by chapter all the way to the end; thank you for granting me time away from you to get this far.

My gratitude is extended to my supportive supervisor Dr. Njabulo Kambule and co-supervisor Prof. Isaac T. Rampedi, who provided guidance and continuous support. Thank you for being the giants that let me stand on their shoulders, enabling me to see what I would have never seen on my own.

I am also thankful to UJStatkon for assisting me with the statistical analysis of my work and Buntu Fanteso for the beautiful GIS maps of the study area.

This work was funded by the National Research Fund, to which I am grateful.

Finally, many thanks to all the participants who voluntarily participated in the research survey.

Abstract

The use of traditional biomass fuels in rural households is alarming, as it prevails even among electrified households. Traditional biomass fuels such as firewood have health, economic, and environmental implications that need to be managed to improve household livelihood. Interventions are required to mitigate the use of biomass fuels and help households' transition to cleaner and sustainable fuels. The aim of this study was to understand the factors influencing the choice of fuel type in households of two of the ten Atok villages in the Limpopo Province and gauge the use of solar photovoltaic as an alternative fuel against the currently used fuels. To achieve the aforementioned, qualitative research methodology was adopted. A random sample of 80 households took part in the survey guided by a questionnaire. Moreover, statistical analyses were conducted to test the relationship between the fuels utilised and factors influencing fuel choice in the area. The study found that electricity, firewood, and candles are the primary fuels used by the community. Additionally, it was ascertained that factors influencing the choice of fuel type include income level, convenience, fuel accessibility, age and level of education of the homeowner, household size, food taste, culture and tradition. Chi-square analyses revealed a statistically significant correlation between age of homeowner and fuel choice, as well as age of homeowner and their dependence on food taste to select a cooking fuel. To determine the most feasible energy fuel (i.e., financially, and economically), a levelized cost of electricity (LCOE) for electricity, firewood, and solar Photovoltaic (PV) was determined for a period of 20 years (2020 to 2040). Albeit the fact that solar PV has positive social, health, and environmental benefits for the rural households of Atok, the finding reflect it to be the costliest option with LCOE of R4,69 ($0.31)[1]/kWh. Ultimately, this research provides essential information for energy authorities and policymakers in guiding, developing, and improving policies related to rural energy development.

KEYWORDS: Traditional Biomass energy; Rural households; Solar Photovoltaic; Energy poverty

[1] Exchange rate: R15.11 to the Dollar

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Acronyms	
AC	Alternate current
ANC	African National Congress
ATA	Alternative Technology Association
BRM	Business Research Methodology
CDM	Clean Development Mechanism
CEI	Climate Emergency Institute
CO_2	Carbon dioxide
COVID	Corona virus disease
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated Solar Power
DBSA	Development Bank of South Africa
DC	Direct current
DEA	Department of Environmental Affairs
DIY	Do it yourself
DME	Department of Minerals and Energy
DMRE	Department of Mineral Resources Energy
DOE	Department of Energy
DOE, FBE	Department of Energy, Free Basic Electricity
DOE, NCCR	Department of Energy, National Climate Change Response
DOE, SoRESA	Department of Energy, State of Renewable Energy in South Africa
EERE	Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ESCO	Energy Services Company
EU	European Union
FAO	Food and Agriculture Organization
FBE	Free Basic Electricity
GACC	Global Alliance for Clean Cook stoves
GHG	Greenhouse gases
GW	Giga watts
IARC	International Agency for Research on Cancer
ICS	Improved cook stoves
IEA	International Energy Agency
IEP	Integrated Energy Plan
INEP	Integrated National Electrification Program
IPP	Independent Power Producers
IPPPP	Independent Power Producers Procurement Programme
IREA	International Renewable Energy Agency
IRP	Integrated Resource Plan
kg/yr	Kilograms per year
km	Kilometers
kw	Kilowatts

Acronyms	
kWh	Kilowatts-hour
LCOE	Levelized Cost of Electricity or Energy
LED	Light Emitting Diode
LPG	Liquefied petroleum gas
MESSAGE	Model for Energy Supply Systems and Their General Effect on the Environment
MJ	Mega joules
mm	Millimeters
MVA	Megavolt amperes
MW	Megawatts
m^2	Meter squared
m^3/s	Meter cubed per second
NASA	National Aeronautics and Space Administration
NDP	National Development Plan
NEP	National Electrification Programme
NGO	Non-government Organization
NO_x	Nitrogen oxides
NREL	National Renewable Energy Laboratory
NSWHP	National Solar Water Heater Programme
NSWHRR	National Solar Water Heating Repair/Replace
O&M	Operational and Maintenance
OCGT	Open Cycle Gas Turbine
PV	Photovoltaic
PVC	Polyvinyl chloride
RDP	Reconstruction and Development Programme
RE	Renewable energy
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
RSA	Republic of South Africa
SA-STTRM	South African Solar Thermal Technology Roadmap
SAWEP	South African Wind Energy Programme
SEA	Sustainable Energy Africa
SEG	Solar Energy Guide
SEI	Stockholm Environment Institute
SETRM	Solar Energy Technology Roadmap
SHS	Solar Home Systems
SO_2	Sulphur dioxide
SSA	Sub-Saharan Africa
StatsSA	Statistics South Africa
SWHs	Solar Water Heaters
TV	Television
TWh	Terawatts hour
UK	United Kingdom
U.S. DOE	United States Department of Energy

Acronyms	
UAS	University of Arkansas System
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
US EPA	United States Environmental Protection Agency
USA	United States of America
USD	United States Dollar
VAT	Value Added Tax
WASA	Wind Atlas South Africa
WHO	World Health Organization
WNA	World Nuclear Association
ZAR	South African Rand
℃	Degrees Celsius

1. INTRODUCTION

1.1. Background of fuels used in rural households.

The use of biomass fuels such as firewood and dung has always being a part of rural households' energy mix. Firewood has been used by rural households for energy needs such as cooking, lighting, space heating, and water heating (Cai & Jiang, 2008). According to the World Health Organization (WHO) (2018), more than 41% of the cooking and heating needs of the world's population are met by solid fuels such as dung, firewood, and crop residues. Notably, in Sub-Saharan Africa (SSA) the use of firewood has been noted to be the most preferred fuel choice amongst rural households (Makonese, et al., 2018). This firewood preference has also been noted in rural households of Limpopo by other researchers (Uhunamure, 2017; Semenya & Machete, 2019). Uhunamure (2017) revealed that more than 50% of the Thulamela Local Municipality's rural households (Limpopo) use firewood than electricity for cooking and heating, even in households that have access to electricity. Likewise, a study by Semenya & Machete (2019) revealed that more than 90% of the Senwabarwana households in Limpopo prefer firewood for cooking, space heating and water heating.

However, the use of traditional biomass fuels has negative environmental, human health, and economic impacts (van der Kroon, *et al.*, 2013; WHO, 2015; WHO, 2018). Particularly, women in developing countries are highly affected by using traditional fuels due to their traditional socio-economic role in households (Murambadoro & Tazvinga, 2013). The negative impacts of using biomass have been highlighted in several papers (Davis, 1998; van der Kroon, *et al.*, 2013; Arku & Brauer, 2018). Wood collection is a time- and energy-consuming exercise and these resources could be utilised for other economic activities (Madubansi & Shackleton, 2006; Dorji, 2012; WHO, 2018). Moreover, collection of wood has potential exposure to violence and personal injury (WHO, 2015). The polluted air inhaled during indoor combustion of firewood has negative impacts on the users' health (WHO, 2016). In cases of using candles for lighting, fires can start and may result in personal injuries. Paraffin stoves can also cause burns and fires (WHO, 2015). Over the years, there has been a need to move away from traditional biomass fuels due to their negative impacts on the livelihood of the users, and thus electrification of rural households is promoted and mobilized.

1.1.1 Electricity in rural households

With evolving technology and economic status, there has been a transition from firewood to cleaner fuels such as electricity. In recent times, households use more than a dozen times more energy than they did in the middle of the 20th century (The electrician careersguide, 2019; IEA, 2020).

Significantly, access to electricity in developing countries is associated with better health care, increased learning rates, and increased household members' economic participation (Davis, 1998; Howells & Alfstada, 2005; Ismail & Khembo, 2015). Furthermore, electricity improves the quality of living in households such as saving time and reducing risks associated with meeting energy needs (Table 1-1). In addition to the list provided in Table 1-1, there are many household electrical appliances that improve the quality of living such as computers, cell phones, electric shavers, lawnmowers, hairdryers, food blenders, and electric doors (Dincer & Abu-Rayash, 2020). These appliances rely on electricity to operate and thus without electricity people would not be able to enjoy all the benefits of modern technology.

Table 1.1: The evolution of household energy functions technology.

Household function	Traditional	Modern
Space cooling	Hand-held fans	Electrical fans, vents
Refrigeration	Dry food to avoid spoils	Refrigerators, freezers
Cooking	Firewood, charcoal	Electrical stoves
Space heating	Fire, blankets,	Heaters, electric blankets
Water heating	Fire	Electric kettles, geysers
Ironing	Charcoal or fire irons	Electric irons
Lighting	Candles, paraffin lamps, fire	Electric bulbs
Washing clothes	Washboards and clotheslines	Washing machines and tumble dryers

In South Africa, there has been an increase (from about 20% to more than 90%) in household electrification rates over the past 20 years (Department of Mineral Resources and Energy (DMRE), 2019). Despite this rate of electrification, the adoption and transition rate from traditional biomass to electricity has been very low. Electricity is used by close to 100% of all electrified South African households for lighting, but very few for other energy needs such as cooking, space heating and water heating (Statistics South Africa (StatsSA), 2019).

More than 80% of South Africa's electricity is produced by Eskom's coal-powered stations (Eskom, 2020). However, the combustion of fossil fuels such as coal has undesirable environmental and health effects. The emission of greenhouse gases (GHG) from coal combustion is contributing to global climate change. Moreover, coal is non-renewable resource and has a finite supply. Despite the benefits of using electricity, the fuel production comes at an environmental cost and has brought upon the need for cleaner and greener efficient alternatives. South Africa's energy policy promotes diversified energy supply, thus the development of renewable energy technologies such as solar power, wind and hydropower (Department of Minerals and Energy (DME), 2003).

1.1.2 Solar PV technology in rural households

Solar energy comes in many forms such as passive solar, solar heating, solar lighting, indirect solar energy, and solar photovoltaic power (Obeng, et al., 2008; Baurzhan & Jenkins, 2016). The use of cleaner fuel technology such as Solar PV can reduce reliance on firewood, greenhouse gas emissions, and power cuts (Findley, 2010; IEA, 2016; Sustainable Energy Africa (SEA), 2016; Abdullah, 2017; Palm, 2018). The following advantages are commonly associated with solar energy (Obeng, et al., 2008; Findley, 2010):

- Reliability
- Silent operation
- Abundant supplies
- Requires no transmission
- Money savings over time
- Profitability in countries that offer rebates
- No monthly operational costs
- Very minimal maintenance costs

In the United States of America (USA), solar PV technology is becoming one of the leading fuels for rural off-grid electrification (United States Department of Energy (U.S. DOE), 2019). However, the initial cost associated with the installation of the system has made solar PV less popular and accepted by most rural households (SEA, 2014). There is growing research that is exploring solar PV as an alternative in rural households. In some cases, the initial cost associated with solar PV is the biggest barrier to adopting the technology. In other areas, the energy policies, solar PV rebates, and knowledge of the solar PV technology are limiting the adoption. However, the solar PV potential for rural households in South Africa can assist in off-grid electrification and households' transition towards green energy (DMRE, 2020).

It is worth noting that the introduction of new energy technologies does not necessarily amount to the replacement of currently used energy fuels but comes as a means of diversifying the energy mix in households. The households' adaptability of new technology and the fuel choice decision-making process is influenced by various factors. These factors include income, accessibility, cost of fuels and appliances, household demographics, location, as well as convenience. An increase in income or wealth level brings about new energy demands that cannot be met with previously used biomass fuels. Therefore, in addition to the currently used fuels, households introduce relevant new energy fuel that can meet their newly emerged energy needs.

Previous studies have uncovered fuel types used in rural households, the energy mix, and the factors influencing fuel choice as well as the adoption of new technology by rural households. However, there is no academic research that focuses on the history of fuel consumption with a view to determining the potential of emerging renewable energy technologies as alternative fuels for rural households of Atok in Limpopo. It is for this reason that this study was conducted to determine the reasons behind fuel type choices, and the factors influencing such choices amongst the rural households in Atok. The purpose of this study was also to gauge solar PV technology benefits against the use of firewood and electricity. The results of this study can provide relevant interventions required to deal with the extensive use of traditional biomass fuels and their effects on the lives of the users.

1.2. Problem statement

More than 70% of the African population resides in rural areas and depend on traditional biomass for energy generation purposes (IEA, 2015; WHO, 2017; Kobayishi & Franks, 2019). South African households' electrification was recorded at just above 84% in 2018 (Department of Energy (DOE), 2018; StatsSA, 2019). Electrification in rural households can be an effective anti-deforestation policy and help mitigate the use of woods and forest residue for cooking (Mandal *et al.*, 2018). The South African Government introduced Free Basic Electricity (FBE) program in 2004, which provides each low-income household with free 50kilowatts hour (kWh) per month (Prasad, 2014; DOE, 2016). The FBE was introduced to allow rural households to fully benefit from the electrification program (Prasad, 2014; DOE, 2016) and provide the basic right of electricity to the households (Republic of South Africa (RSA), 1996). However, South African rural households continue to use, despite having access to free electricity of 50kWh per month, traditional biomass fuels, such as wood; which have negative health, socio-economic, and environmental impacts (Davis, 1998; Madubansi and Shackleton, 2006; van der Kroon, *et al.*, 2013; Weber & Sotelo Montes, 2017; Arku & Brauer, 2018).

Electricity affordability is the leading factor influencing fuel choice in rural households. Thus, electrified rural households continue to use traditional biomass fuels because they cannot afford to purchase and power electrical appliances (Madubansi & Shackleton; 2006; Madubansi, 2007; Sankhyayan & Dasgupta, 2019). The fuel choice in rural households is influenced by factors such as household income, food taste, tradition and culture, age and marital status of homeowners, access to electricity, and household size (van der Kroon, *et al.*, 2013; Makonese, 2017; Uhunamure, 2017)

It has been established that the usage of firewood and candles in Limpopo households (both electrified and non-electrified) is high (Uhunamure, 2017; Semenya & Machete, 2019). A low proportion of rural households in Limpopo rely on electricity for cooking (Makonese, 2017; Uhunamure, 2017). It has been estimated that about 75% of electrified households use wood for cooking and more than 80% of non-electrified households use wood for cooking (DOE, 2009). Similarly, the extensive use of firewood has been observed in Atok villages, although some of these households have access to electricity.

The use of fossil fuels in electricity generation has negative environmental effects such as atmospheric pollution and deforestation, and therefore it is not sustainable for the future (Ahmad & Imran, 2018; Alam, et al., 2018; Baek, et al., 2020) It is thus necessary to consider alternative energy sources for rural households in South Africa, and the world for sustainable development. Globally there is a growing impetus for the adoption and transition towards the renewable energy (WHO, 2018; Energy Efficiency and Renewable Energy (EERE), 2019). Approximately 80% of areas in South Africa experience 2 500 hours of sunlight per year, with solar radiation average of between 4.5 and 6.5kWh/m^2 (DOE, 2018). This proves that South Africa has sufficient radiation to enable households to meet their energy needs using solar PV systems (Matasane, 2014). However, the success of off-grid households means installing energy storage systems alongside the solar PV systems. The initial cost associated with the solar and storage system is relatively high for many South African households (Baurzhan & Jenkins, 2016). Solar power technology demand is increasing while the production of the technology is improving in terms of efficiency, as well as the decrease of cost to the end-user (DOE, 2018).

Solar PV technology can be explored as an alternative energy source for rural households of Atok due to the availability of sufficient radiation in the area as well as its decreasing cost. Therefore, this study examines solar PV as an alternative energy source with a view to determine the benefits of investing in solar PV systems in comparison to the fuels that are currently used in rural households of Atok. A comparison of costs, advantages, and disadvantages of solar PV against fuels currently used in Atok rural households will be explored to determine the best investment decision to make when it comes to sustainable, affordable, and clean energy.

The results of the fuel comparison will provide ways in which Atok households can move away from traditional biomass and conventional fossil fuels, towards the use of renewable energy thus benefitting from solar energy technology. It is vital to find the factors affecting the fuel choice decision making and acknowledge that the electrification of these villages alone is not a sufficient intervention in moving the households to cleaner energy sources. Knowledge of the fuel choice and preferences of the residents are vital to energy planning to ensure that the needs of the residents are not neglected. Given the constraints that impact the natural environment negatively, this study seeks to establish an understanding of the different reasons behind fuel choices and to gauge currently used fuels against solar PV as an alternative fuel.

1.3. Research aim

The study aims to investigate the possible impact of utilizing solar photovoltaic as an alternative energy source as compared to the current traditional energy sources in rural households in Atok.

1.4. Research objectives

The objectives of this study are to:

1. Determine the nature of energy needs and types of energy sources currently used to meet the basic rural household needs, as well as the factors impacting the choice of energy sources in Atok.

2. Uncover social, financial, and environmental implications associated with the fuels currently used in these households.

3. Assess and compare the social, financial, and environmental impact of applying solar photovoltaic technology, in relation to currently used traditional energy fuels in these households.

1.5. Description of study area

The study area is Atok, which is a mining community situated 70kilometers (km) west of Burgersfort and 85km South-East of Polokwane. It is located within the Fetakgomo Tubatse Local Municipality in the Greater Sekhukhune District in the Limpopo Province, South Africa (Figures 1-1 and 1-2). Specifically, the current study focused on the Maropeng (24°18'25.6"S 29°51'29.0"E) and Mogabane (24°19'17.3"S 29°52'51.2"E) villages. The two villages are characterized by a population that is 100% black and the predominant language is Sepedi (StatsSA, 2011). The total number of households for both villages is 261, with an average household size of 5.2 members per household (see Table 1-2) (StatsSA, 2011). Figure 1-2 shows the households setting, types and spacing between houses, as well as the vegetation of the area.

Table 1.2: Statistics of Mogabane and Maropeng (StatsSA, 2011)

Characteristics	Mogabane	Maropeng
Total Population	757	605
Number of households	151	110
Female-headed household	51.3%	42.3%
Male-headed household	48.7%	57.7%
Average household size	4.9	5.5
Working Age (15-64)	58.4%	61%
Elderly (65+)	5.2%	3.8%
Young (0-14)	36.5%	35.2%
Female	53.1%	52%
Male	46.9%	48%
No schooling above 19	20.5%	17%
Higher education	5.4%	2.5%
Matric aged above 19	23.3%	35.5%
Housing owned	88.1%	31.5%
Flushing toilets	0.7%	0.9%
Piped water inside households	0.7%	0%
Electricity for lighting	94%	98.2%

It has been close to 20 years that the households considered for this study have been electrified. The households' electricity purchase is through prepaid meters. To date, 95% of these households have access to electricity. Moreover, more than 70% of households have refrigerators, radios, televisions, cellular phones, and electric/gas stoves. Electricity is used by approximately 56% of households for cooking, and over 94% for lighting (StatsSA, 2011). More than 94% of the households were using electricity for lighting in 2011 (StatsSA, 2011), however this number has since decreased due to newly built houses that are yet to be electrified. As such, candles continue to be used for lighting by more than 43% of the population in the area (StatsSA, 2011).

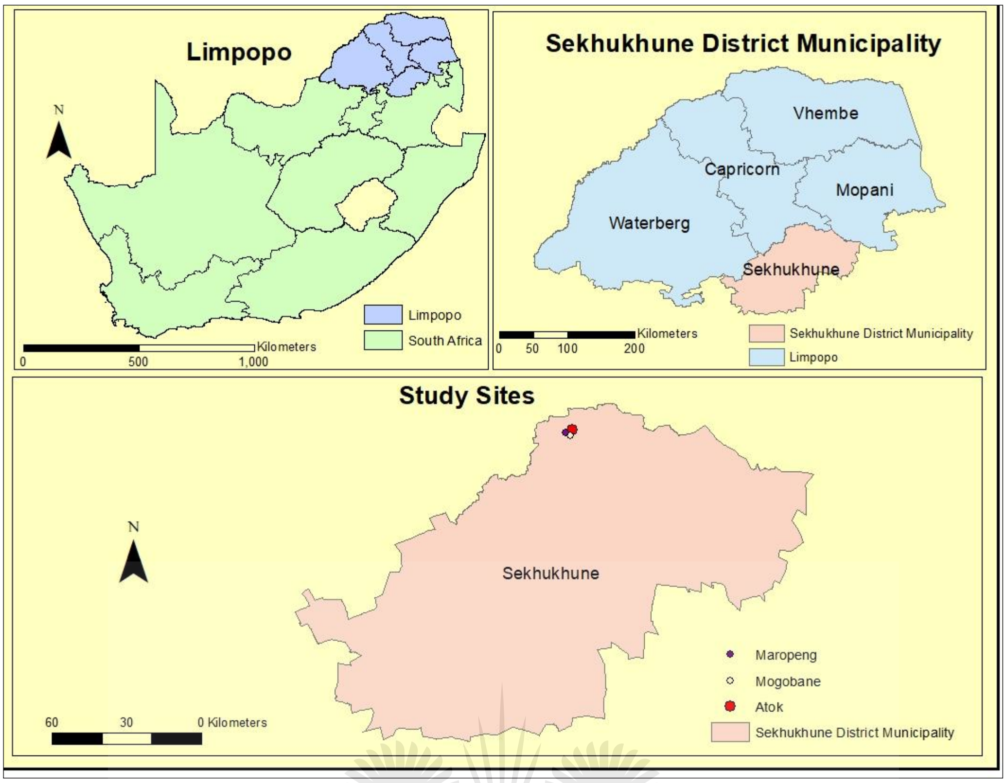

Figure 1.1: Map of the study area (GIS, 2020)

Figure 1.2: An overview of Atok households' structure.

Majority of the population in Atok does not have access to the internet (StatsSA, 2019). The community obtains water from local water schemes and dams, with only 13.6% of households that are using borehole water. The annual income is between R9 600 and R153 800 per household (StatsSA, 2011). More than 22% of Mogabane households are without income, while Maropeng stands at more than 10%. More than 50% of the household's monthly income is less than the minimum monthly wage of R3500 (StatsSA, 2011). Wood is used by 42% of the households for cooking and 43% for heating (StatsSA, 2011).

1.6. Structure of the research report

This dissertation has been compiled and structured as follows. Chapter 1 introduces the study and lays the theoretical context. It also provides the rationale and justification of the research while providing the statement of the research problem, aim and objectives. Chapter 1 ends with the description of the study area. Chapter 2 is based on the literature study that pertains to the research problem. The review focuses on fuel types used in rural areas, energy poverty, impacts of biomass fuels, factors influencing fuel choice, and case studies of solar photovoltaic technology application in rural households.

Chapter 3 is the methodology section in which the research design is outlined; the decision to use mixed methods is explained; and data collection, storage, and analysis are detailed. Data is presented and analysed in chapter 4: The data collected on household demographics, fuel use, factors influencing fuel choice are presented. The results on the factors influencing fuel use, implications of using firewood and electricity, interventions required to move towards cleaner energy, and the use of solar PV as an alternative are discussed in chapter 5. The section also discusses input data of solar PV, firewood, and electricity into the LCOE calculations. The study is concluded in chapter 6. Suggested future work is detailed in chapter 7.

2. LITERATURE REVIEW

2.1. Introduction

To better understand and comprehend the study, a literature review of relevant studies was conducted. This section outlines some of the findings from different authors with similar or related work on fuel type and factors which influence the choice, the implications associated with currently used fuels, solar PV benefits and barriers in rural areas. Section 2.2 discusses the energy sector in South Africa. Included in this discussion are details of the electricity grid-connection and other energy sources such as renewable energy technologies. Section 2.3 deals with fuel types used in rural areas, where the state of energy poverty is discussed. The traditional biomass fuels, modern technologies, and alternative energy fuels such as renewable energy technologies and improved cook stoves used in rural areas are explored in section 2.3. The section further covers the investigation of social, health, financial and environmental implications associated with currently used fuels. Section 2.4 covers case studies of solar PV technology application in other areas, the success and challenges faced with implementing the technology. All the relevant South African energy policies such as White Paper, Green Paper and Integrated National Plan are detailed in section 2.5. The chapter is concluded in section 2.6.

2.2. The energy sector in South Africa

In South Africa electrification dates to the 19^{th} century, majority of the population only started benefiting from the programme post-1994 (Kambule, 2018). Electricity for All Programme was launched in 1988 by the National Electricity Forum (NEF), which was aimed at improving the socio-economic status of South Africans by providing households with electricity (DME, 1998). This programme achieved an electrification rate of 36% by 1993, which was still insufficient and did not include most of the South African population, i.e., black people (Adam, 2010; Kambule, 2018).

Low-income households were previously neglected in terms of energy needs and electrification. The creation of a new industrialised urban community to meet the needs of the industrial sector and a privileged white minority was a priority of the governing body prior to 1994 (DME, 1998; Kambule, 2018). The inequality in wealth as a result of past social and economic policies resulted in a service backlog, and no electricity or inadequate electricity for the less privileged (Amra, 2013). Majority of the electrified households could only afford to use electricity for lighting and entertainment at that time. Such households had to rely on fuels such as coal, firewood, paraffin, batteries, candles, and liquified petroleum gas (LPG) (DME, 1998). South Africa's apartheid era came to an end and a democratic era was born in 1994. The governing party African National Congress (ANC) made it part of their mandate to increase electrification in previously disadvantaged communities by introducing the National Electrification Programme (NEP) (African News Agency, 2018; Kambule, 2018). The NEP was introduced and implemented successfully, increasing the electrification rate from 36% to over 90% in 2019 (DMRE, 2019). During the year 2003, Free Basic Electricity (FBE) policy was gazetted by the South African government, which aimed at providing qualifying households with free electricity of 50kWh per month. The FBE was introduced to assist households with their monthly expenses (Davis, 1998; DOE, 2009).

The energy sector in South Africa is comprised of these supply sub-sectors: coal, electricity, gas, liquid fuels, nuclear, and renewable industries. The energy mix has evolved over the past few years from coal being the dominant (over 80%) energy source, to renewables contributing more than 30% to the energy mix (Mashele, 2019) as shown in Figure 2.1. The demand sector includes households, agriculture, transport, mining, commerce, and industry. Table 2-1 gives details of the various technologies, their advantages as well as disadvantages.

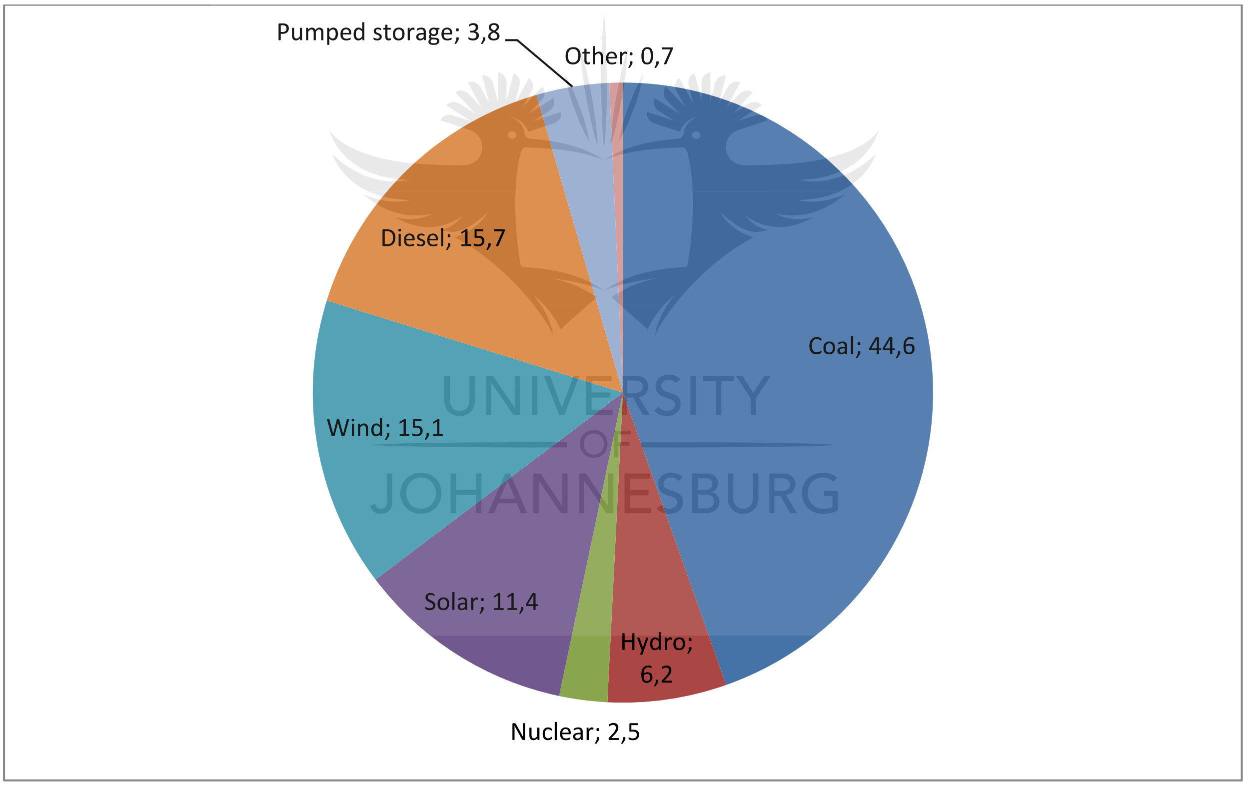

Figure 2.1: South African energy mix in 2018 (DMRE, 2019)

Table 2.1: South African energy technologies, their advantages and disadvantages (DOE, 2018; DMRE, 2020; Eskom, 2020)

Source	Advantages	Disadvantages
Coal	Cheap, reliable and abundant. Generation technology is well understood (tried and proven). Cost-effective and energy efficient.	Emits smoke, nitrogen oxides, sulphur oxides, lots of ash, mercury, and greenhouse gases. Air pollution. Coal stations must be sited next to coal fields. The process of building a coal-fired power station is long and expensive.
Nuclear	Clean. Concentrated, thus only small amounts of it required. No Carbon dioxide (CO_2) emissions. Easy to manage and store waste. Sustainable because of lots of uranium and thorium in the ground and sea. Exceptionally reliable. Has a high load factor. Economic and cheapest source of electricity (e.g., in France and the USA). Can be sited anywhere. Safe.	Public perception that nuclear power and nuclear weapons are one thing. Corruption related to the current nuclear deals. Cannot be easily switched on and off.
Hydroelectricity	Clean, reliable, and proven. Continuously available power. Long-lasting and robust technology. Limited maintenance. Low running costs.	Lack of suitable rivers. Potential environmental problems from dams. Marine life disruption and dislocation of populations.
Gas	Clean, reliable, and proven. Flexible, quick, and cheap to build.	Expensive to run. Highly dependent on the price and availability of gas. Gas from Mozambique may not always be available and affordable to South Africa. Quantity and quality of the Karoo shale gas is unknown.
Solar	Clean and renewable. No direct emissions. Can be sited anywhere. Suitable for low energy use such as lights and television. No transmission required. Silent in operation.	Expensive. Unreliable. Unpredictable. Large resources required per kWh. Cannot be used for baseload electricity. Quality and stability are a problem. Concentrated Solar Power (CSP) storage is very costly.
Wind	Clean and renewable. No harmful gases emission. Highly effective in the coastal areas. Can be placed offshore. No disruptions to other activities. Environmental impacts are manageable.	Wind fluctuates, does not always blow. Unreliable. Expensive to build. Noisy generators. Kill birds and bats. Jobs and industry for manufacturers only, such as those in Denmark. Unsightly and obtrusive.

Source	Advantages	Disadvantages
Biomass	Renewable energy source. Reduced Nitrogen Oxides and Sulphur Oxides emissions. The cost of fuel can be zero or negative when waste is used.	High building capital cost. Requires agricultural land for dedicated fast-growing crops. Must be sited in proximity of the fuel source (fuel transportation is costly).
Pumped Storage System	Water is renewable. No emissions during electricity generation. Allows energy storage in a form of water.	SA has a few suitable locations for the system due to its dryness. Environmental impact by river constructions.

2.2.1. Electricity

Africa's electrification rate is relatively low compared to the global electrification rate of 90%, with Sub-Saharan Africa rate at just above 48% (Worldbank, 2019). Approximately 580 million African people were without electricity in 2019, which was a great decline from a peak of 610 million people in 2013 (IEA, 2020). South Africa provides approximately 40% of Africa's electricity and has been one of the world's four cheapest producers of electricity until recently (IEA, 2018). South Africa's electricity market is dominated by the national power utility (Eskom), which produces more than 80 % of the country's electricity (Eskom, 2020). Municipalities and dealers, as well as private generators, supply the rest of the electricity used in the country (Ratshomo & Nembahe, 2018). In terms of generation capacity, Eskom is the eleventh largest power utility in the world, ranks ninth in terms of revenue, and boasts the world's largest dry-cooling power station (Eskom, 2020). The utility directly sells electricity to some 3 million residential, 18 000 commercial, 70 000 agricultural and 6 000 manufacturing customers, respectively, which is a total of more than 6.2 million customers (Eskom, 2020).

Eskom is the dominant producer of energy, with a generation system consisting mainly of coal-fired power stations, with some gas-fired, hydro, pumped power storage, and a single nuclear power plant (Eskom, 2020). In 2019 there were 46 665 employees within Eskom, including subsidiaries (Eskom, 2020). Eskom produces, transmits, and distributes electricity to manufacturing, mining, commercial, agricultural, and residential customers in South Africa and to municipalities that, in turn, redistribute electricity to businesses and households in their regions. The company also purchases electricity from Independent Power Producers (IPP) in the form of various agreements (IPP, 2017; Eskom, 2020).

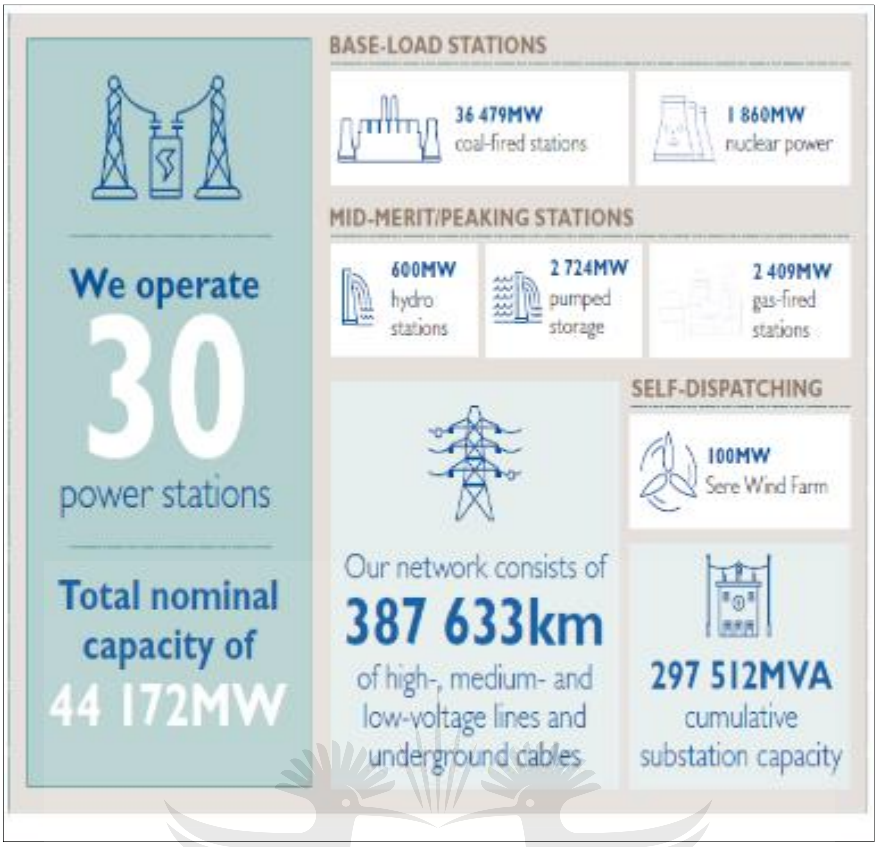

Figure 2.2: Eskom generation, transmission, and substation capacity in 2019 (Eskom, 2020)

Electricity generation in South Africa is through Eskom (the state-owned electricity utility), IPP (in partnership with Eskom), municipal entities, and the auto generators. Municipalities own 22 small power stations and gas turbines, which account for just 4% of the national generation capacity and typically operate on low load factors. Private generators comprise the remaining 1% of the power generation capacity (Ratshomo & Nembahe, 2018). The auto generators are industries which generate electricity for their use, such as Sasol, the pulp mills, sugar refineries, metallurgical industries and Mossgas. Eskom operates 30 power stations with a gross nominal capacity of 44 172Megawatts (MW) (Eskom, 2018); different fuel power plants and their contributions to the total capacity are shown in Figure 2-2. Table 2-2 shows the non-Eskom power plants and their installed capacity, which was approximately 4 389MW in 2017 (DOE, 2018).

Table 2.2: South Africa's non-Eskom power plants (Lucas, 2017)

	Installed Capacity (MW)
Kelvin	160
Sasol Infrachem Coal	125
Sasol Synfuel Coal	600
Other Non-Eskom Coal	18
Other NonEskom Gas	16
Sasol Infrachem Gas	175
Sasol Synfuel Gas	250
DOE IPP	1005
Colley Wobbles	65
Other Non-Eskom Hydro	12
Cahora Bassa	1500
REBID Hydro	19
Steenbras	180
Sappi	144
Mondi	120

South Africa has only one nuclear power station, the Koeberg nuclear plant, which caters for approximately 5% of the country's electricity. Koeberg nuclear plant was commissioned in 1984-1985 and is located 30km north of Cape Town. This is the only nuclear power station in Africa. It holds the record for the longest continuous operating Eskom unit of 454 days without an interruption (Eskom, Nuclear Energy: Koeberg Power Station, 2017; World Nuclear Association (WNA), 2017). The nuclear plant operating method is shown in Figure 2-3. There is a public perception that nuclear radiation is very dangerous, but the granite kitchen tops and tombstones around Koeberg beach were found to be more radioactive than the power station (Lucas, 2017).

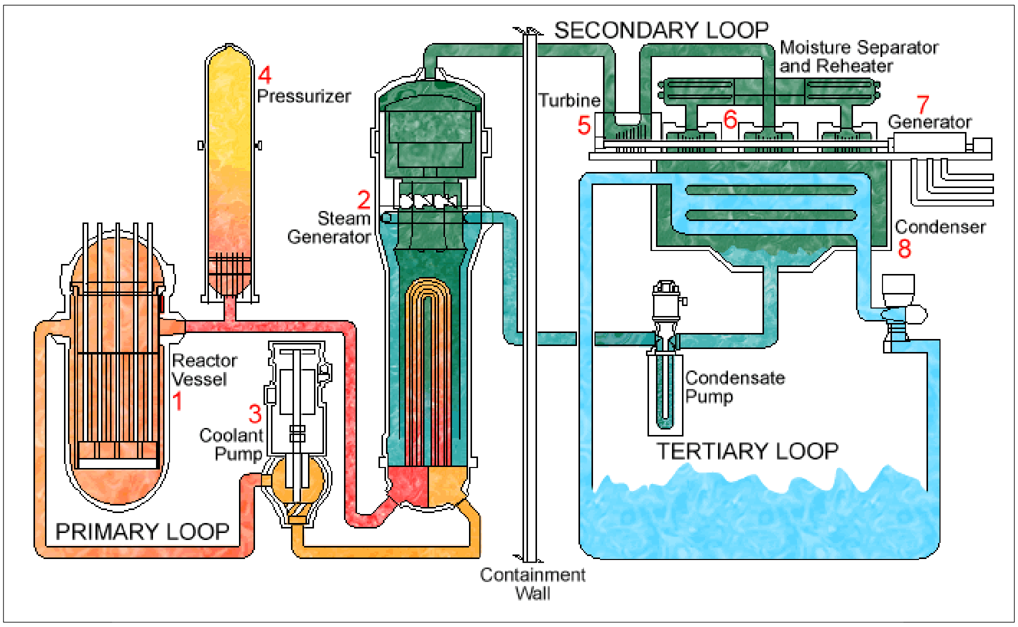

Figure 2.3: Koeberg nuclear plant operating method (Eskom, 2017)

The national transmission system is owned and operated by Eskom. Electricity is distributed to the end-user by Eskom and municipalities. All of Eskom's electricity generation sources are highlighted in Figure 2-4 where the great contribution by sources other than coal are shown, including some renewable energy technologies (Eskom, 2020).

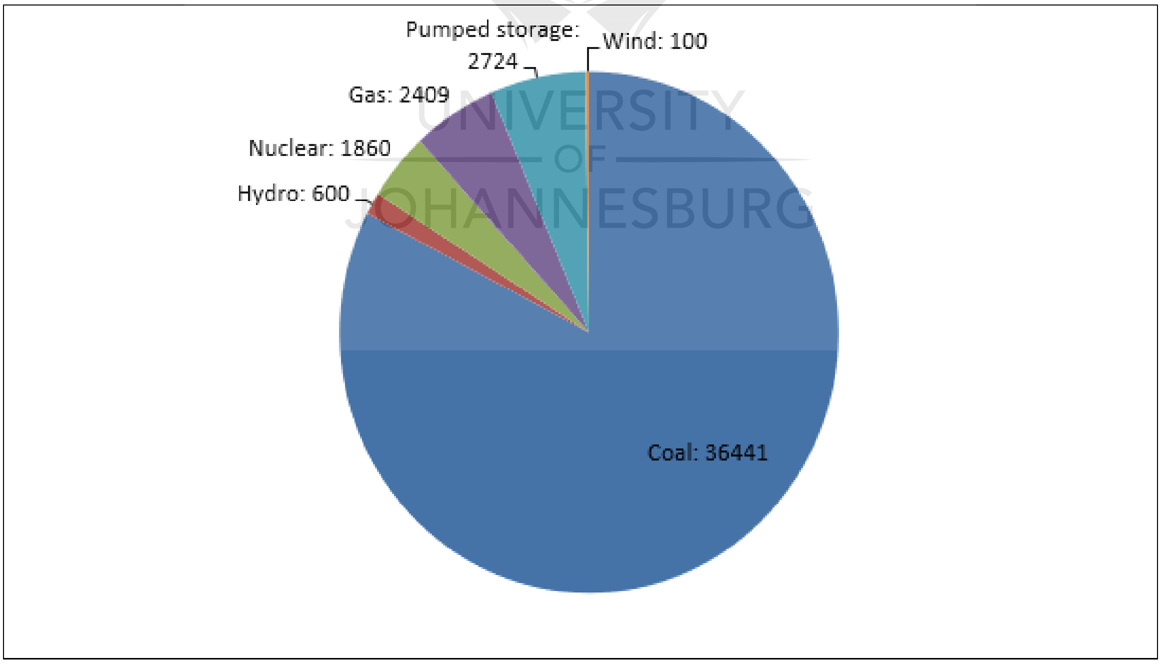

Figure 2.4: Eskom electricity generation power plants mix in 2019 (Eskom, 2020)

2.2.2. Renewable energy technologies

Renewable energy sources tend to be the least costly way of achieving universal access to electricity in many areas: in addition to the rising grid-connected generation of electricity from renewables, the decreasing cost of small-scale solar PV for stand-alone systems and mini-grids, it is crucial to helping millions of people have reliable access to electricity (IEA, 2020). This is especially the case in remote rural areas of African countries, where many people are still deprived of access to electricity. Spain is introducing new energy-related technology, with particular emphasis on solar energy, and is updating European and Spanish regulations on building and promoting renewable energy, intending to concentrate the world's attention on the implementation of policies geared towards optimum energy efficiency and the use of renewable energy (Tam, *et al.*, 2017).

South Africa has an abundance of fossil fuels in the form of coal, hence the many existing and newly built coal-fired power stations (Steyn, 2013). South Africa is the 12th most lucrative investment in renewable energy. South Africa has one of the most active renewable energy programs, making it a popular destination for energy investment (IPP Projects, 2019). There has been a rapid increase in small and medium-sized businesses focused on renewable energy. Large-scale energy project developers from many parts of the world, accompanied by several local and international investors are willing to build a new investment frontier (Ecozoom, 2019; DMRE, 2020); not to mention the development of the country's first large-scale commercially powered renewable energy projects (IPP Projects, 2019). Solar-powered electricity generation and solar water heating have become competitive owing to the increasing cost of coal-fired power generation and the declining cost of solar power systems (DMRE, 2020; Eskom, 2020). It is worth noting that with the ever-increasing cost of conventional fossil-based energy, renewable energy is becoming a viable alternative.

The green economy was identified by the South African government as one of the 12 drivers of jobs that could help generate 5 million additional jobs by 2020, with up to 300 000 new direct jobs projected in the fields of natural resource management and renewable energy. A 70/30 potential power generation capacity split between Eskom, IPPs, and private sector involvement in the electricity industry was approved by the Cabinet in 2003 (DMRE, 2019). The National Development Plan (NDP) mandated the construction of an additional 10 000MW of electricity capacity to be built by 2019 compared to the baseline of 44 000MW in 2010 (DMRE, 2019). The Integrated Resource Plan (IRP) 2010-2030 established the desired energy mix to meet electricity needs over a 20-year planning period to 2030. IRP targeted 7 000MW of renewable energy generation to be operational by 2020, to maintain the national commitment to move to a low-carbon economy (DMRE, 2019).

An increase in population results in an increase in energy demand. A rise in energy demand without proper energy planning and infrastructure can result in more load shedding and power outages (Eskom, 2018). South Africa can reduce the power demand from the grid electricity supplier by investing in renewable energy solutions (Ouedraogo, 2017; Israel-Akinbo, *et al*., 2018). Investing in renewable energy technology will not only improve energy security supply but help households in better planning of their energy services activities as availability of energy carriers will be well known (Israel-Akinbo, et al., 2018). Modern energy services can improve the quality of living through better health, better environment and relief from intensive hard labour associated with the use of traditional biofuels (Rahman, *et al.,* 2014; Sen & Bhattacharyya, 2014; WHO, 2015).

2.2.2.1. Renewable Energy Independent Power Producer Procurement Programme (REIPPPP)

The Renewable Energy Independent Power Producer Procurement Program (REIPPPP) was developed by the DOE in conjunction with the National Treasury and the Development Bank of Southern Africa (DBSA) at the end of 2010 (DOE, 2018). REIPPPP is one of the urgent interventions of the South African government to improve the country's power generation capacity. The program seeks to put additional energy into the electricity system through private sector investments in wind, solar PV, concentrated solar power (CSP), biomass and small hydro technologies (IPP Projects, 2019).

Solar energy as one of the technologies promoted by the REIPPPP can be used to produce electricity, heat water, as well as heat, cool and light buildings. The solar PV system consists of panels, controller, and batteries (Ranaboldo, et al., 2014; Azimoh, et al., 2015). The panels absorb the sunlight and convert the photons into electrons that generate direct current (DC) electricity. The controller protects the overcharging and deep discharging of the batteries. The batteries store the generated energy for use when generation is not possible due to insufficient sunlight (Ranaboldo, et al., 2014; Chauhan & Saini, 2015). As such, the batteries must have sufficient capacity for night use and rainy days. Electrical appliances use alternate current (AC), so the inverter converts DC to AC for use in households (Ranaboldo, et al., 2014). Alternatively, sunlight can be gathered and concentrated with mirrors to create a high-intensity heat source that can be used to produce energy utilizing a steam turbine or a heat engine (DMRE, 2020).

CSP technology uses focused sunlight i.e., produces solar power by using mirrors or lenses to focus a wide area of sunlight on the receiver (National Renewable Energy Laboratory (NREL), 2017). The concentrated sunlight energy is then converted into high-temperature heat (Figure 2-5). This heat (solar thermal energy) moves through an electrical generator as the steam drives a turbine that generates electricity (SEG, 2017; DMRE, 2020). A CSP plant comprises of two divisions: 1. Collect solar energy and convert it to heat and 2. Convert heat energy into electricity (Eskom, 2017; DMRE, 2020). Some of the CSP projects in South Africa are Bokpoort, Ilanga I, Khathu Solar Park, KaXu Solar One, Shi Solar One, Khi Solar One and Redstone Solar Thermal Power Plant. The first mentioned five are parabolic trough technology and the last two are power towers (NREL, 2017).

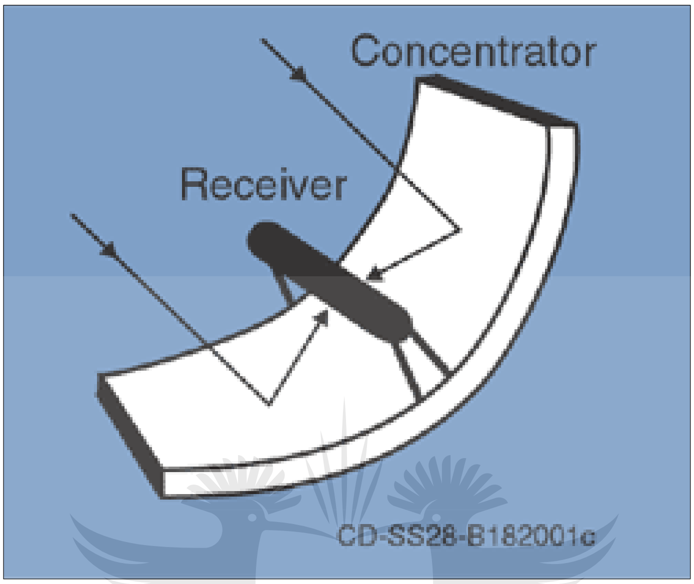

Figure 2.5: CSP parabolic trough system (SEG, 2017)

Biogas is a mixture of gasses formed by the breakdown of organic matter in the absence of oxygen, consisting primarily of methane and carbon dioxide, and may contain small quantities of hydrogen sulphide, and moisture (Rai, 2006). Biogas power is generated by a slurry of waste products which include raw materials such as agricultural waste, municipal waste, plant material, wastewater, green waste, food waste and animal/human sewage waste (Eskom, 2018). In a biogas plant, it takes about three weeks for the gas to develop after which it is released harmlessly to the atmosphere. The required gas generation commences, and the plant is fed every day with ±25lt of dirty water and methane-containing- solids to form a lurry (IPP Projects, 2019). Domestic digesters are bio-digesters where waste is fed into the digester and mixed with water to create gas that can be used for electrical power (Munganga, 2013). Most common installations in South Africa are PVC (Polyvinyl chloride) digester, concrete digester, and plastic bag (bio-bag). Domestic digesters can be used for cooking, lighting, and sanitation mostly in the rural areas (IPP Projects, 2019). Some small biogas projects in SA with their capacity include Humphries Boerdery outside Bela-Bela (30kW), Abattoir-Jan Kemdorp (100kW), Cullinan (190kW), Robertson (150kW), Jacobsdal (150kW) (Munganga, 2013; IPP, 2017). Large scale installations include Chloorkop landfill gas project, Ekurhuleni landfill gas project, Robinson Deep, Bronkhorstspruit Biogas Plant and Cape Dairy Biogas Plant (Munganga, 2013).

Biomass generation of electricity uses waste from human and natural activities as fuel. This can be done either by burning biomass to increase steam that powers a steam turbine or by turning the biomass into gas then using gas to drive an electrical generator (IPP Projects, 2019) The waste includes methane captured from landfill sites, agricultural residues, energy crops, wood waste, paper trash and municipal solid waste (Eskom, 2017). The waste is collected and transported by big trucks to a biomass plant. At the plant, the waste is fed into furnaces and burned. The heat generated boils water to create steam. The steam energy produced rotates turbines and generators to generate electricity (IPP Projects, 2019). The gas can also be used in a gas engine to turn the gas energy into electricity and heat (IPP Projects, 2019) Firewood is the largest source of energy from biomass, typically obtained from trees. However, the use of firewood is unsustainable because new trees are not planted to replace those used. Therefore, firewood derived in this manner cannot be properly classified as renewable (Ratshomo & Nembahe, 2018).

Landfill gas technology converts waste into electricity. Household waste, collected by municipalities, is disposed of in a landfill (Harry, 2015). The landfill is covered such that the methane gas does not escape. Microorganisms that reside in organic products, such as food waste, paper or yard clipping, cause the waste products to decompose and generate gas (DMRE, 2019). The generated gas normally comprises of approximately 60% methane and 40% carbon dioxide. Methane gas is fuel and when harvested and used in special gas-fired engines it can be used to power an electrical generator (IPP Projects, 2019). The gas is transported via pipes to the plant where it is burned, and electricity is generated (Harry, 2015).

A hydroelectric system generates electricity from water without any actual water consumption (Hunt, et al., 2014). Water is stored in an upper reservoir and passed through a turbine and generator set and released back into the river downstream (Figure 2-6). The water is only redirected or channelled to pass through the turbines and generators, rotating them to generate electricity. Hydroelectric power stations have the advantage of reacting quickly to fluctuating power demand (Eskom, 2017; Hunt, et al., 2014). Small hydro turbines transform kinetic energy from falling or flowing water to rotational mechanical energy in the shaft power. This mechanical energy is used to drive a generator to generate electricity (IPP Projects, 2019).

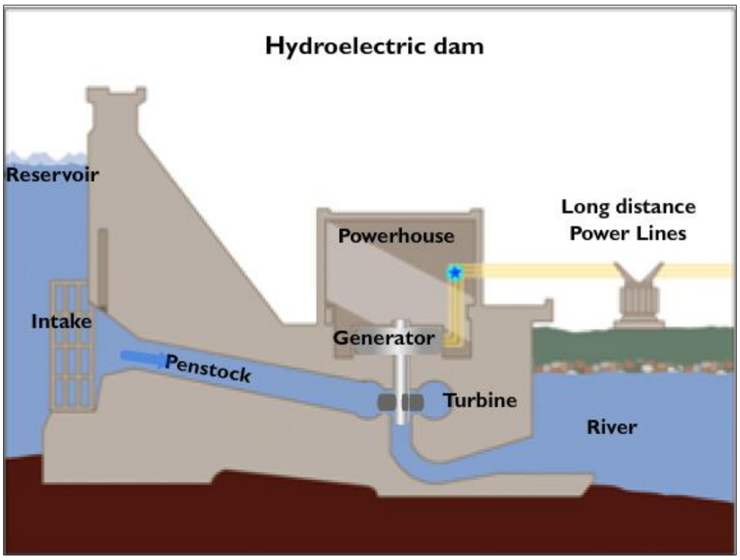

Figure 2.6: Hydroelectric power generation schematic diagram (Eskom, 2017)

Pumped storage is a reversible pump/turbines system. To generate electricity water moves from the upper reservoir through the turbines to the lower reservoir where it is stored (Figure 2-7) (Eskom, 2017). The water flow rotates the turbines which are connected to a generator which then converts the rotational energy to electrical energy (Hunt, et al., 2014). When there is enough electricity, the system is tuned into the pump mode where water is pumped back to the upper reservoir from the lower reservoir, stored there until electricity generation is required again (García-González, et al., 2008; Eskom, 2017). The system can be used to regulate the voltage and supplement water supply when not generating electricity (Eskom, 2017).

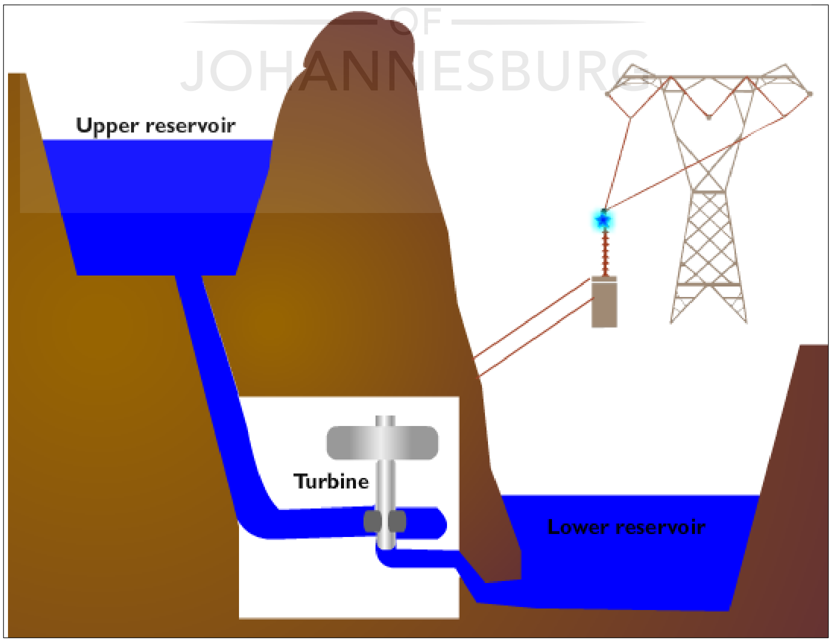

Figure 2.7: Pumped Storage System setup (Eskom, Pumped Storage, 2017)

South Africa has two pumped storage systems, both run by Eskom, namely, Palmeit Pumped Storage Scheme and the Drakensberg Pumped Storage Scheme. Palmeit pumped storage scheme is located 2km upstream of the Kogelberg Dam wall on the Palmiet River in Western Cape (Eskom, 2017). Palmeit consists of two 200MW units to give it a capacity of 400MW. This station can pump additional water from the Palmiet River via the Rockview Dam to the Steenbras Dam to supplement the Cape Town water supply (Eskom, 2017). Drakensberg Pumped Storage Scheme is in KwaZulu Natal and has been operational since 1981. The station is constructed entirely underground with only lift shaft buildings, a dam wall and transmission lines visible on the surface (Eskom, 2017). This storage system has four reversible pump turbines (with a capacity of 250MW each) situated 172m below ground level. The Drakensberg scheme was designed to generate electricity for 10 hours per day and pump water back to the top dam for 9 hours per day with all its 4 units (Eskom, 2017). The Drakensberg scheme can transfer $20m^3/s$ of water from the Kilburn Dam to the Sterkfontein Dam into the Vaal River to supplement Gauteng water supply (Eskom, 2017; DMRE, 2019).

Wind energy is a naturally available source which is in abundance in the coastal areas. The wind turbine is a rotary device that produces energy from the wind (Eskom, 2020). A wind turbine as the name suggests, functions when there is wind blowing, i.e., the air blowing propels the rotor blades. The blades rotate and along with it an axle that is attached at the centre of the blades (Figure 2-8). The axle carries over the energy to a gearbox and to the generator where the rotational energy is converted into electrical energy (Ledger, 2017). This electrical energy produced in in high voltage and is converted by the transformer into a more useable voltage (IPP Projects, 2019). More than 80% of the land area of South Africa has wind resources to encourage the growth of economic wind farms with annual load factors of more than 30% and a total wind power capacity of 67 000GW are comparable with solar power potential (Jain & Jain, 2017). South Africa needs 250Terra watt hour per year (TWh/y) of electricity, all of which could be generated from wind farms with a combined capacity of 75GW over 0.6% of the land area of the country (Jain & Jain, 2017; DMRE, 2019). Most South African wind turbines have a capacity of 1.8 to 2MW. Klipheuvel and Darling Wind farms are some of the wind power projects in SA (DOE, 2018). The biggest disadvantage of wind turbines is the effect they have on birds and bats.

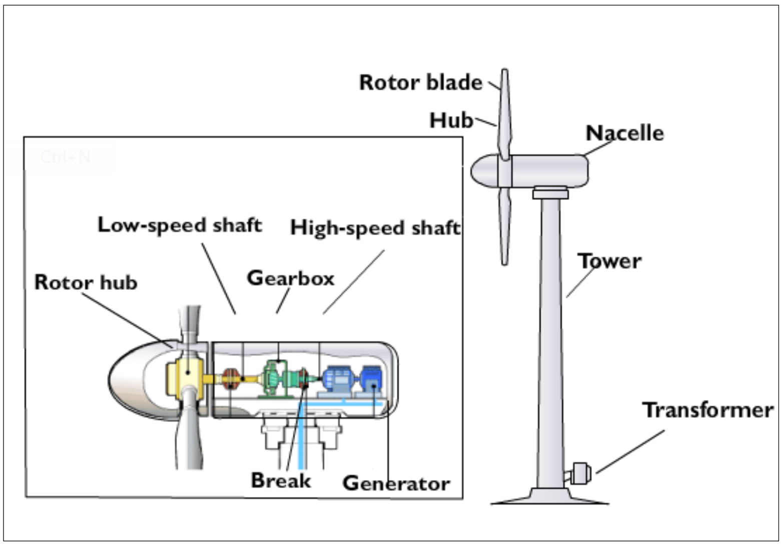

Figure 2.8: Wind turbine electricity generation structure (Eskom, 2017).

The program has gained international praise for its fairness, openness, and certainty. South Africa is the leading candidate for increased use of renewable energy due to the plentiful wind and sun resources (solar power) available. The REIPPPP has been one of the nation's most successful implementations in promoting diversity in energy carriers, particularly renewable energy (DOE, 2018; DMRE, 2019).

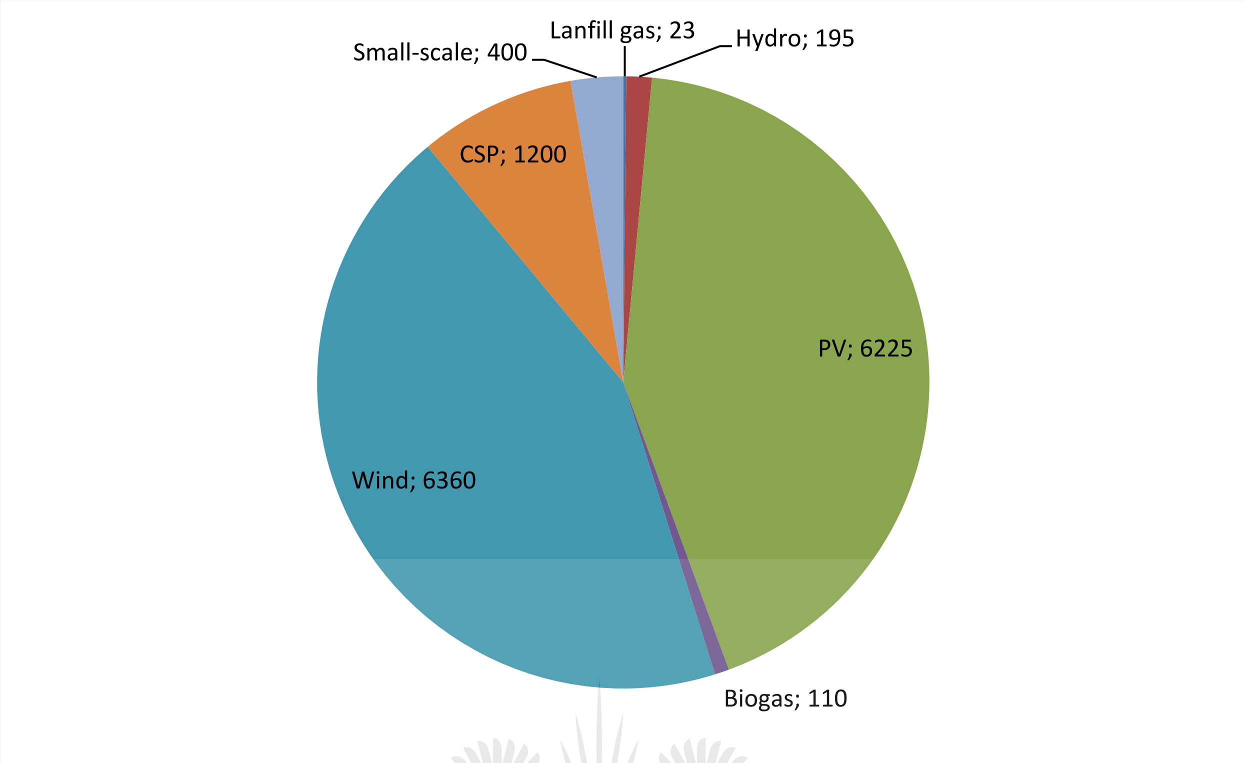

Figure 2.9: New electricity generation from renewables as gazetted by the DOE in 2011 (DME, 2011).

2.2.2.2. Solar Energy

Solar power is a clean way of producing energy from solar radiation. Solar PV systems usually have batteries for energy storage, and a charge controller to regulate the power in and out of the battery (Findley, 2010). This technology can be used for appliances such as refrigerators, microwaves, lightings, overhead projectors, radios, computers, televisions, and water pumps (Eskom, 2017; Palm, 2018).

Investing in a solar power system has environmental benefits such as reducing greenhouse gases emissions, thus contributing to the global warming mitigation (Findley, 2010; IEA, 2015; Palm, 2018). Solar energy installation is reliable, silent in operation, abundant, require no transmission, offer money savings over time, has no monthly operational costs and very minimal maintenance cost, and can be profitable in countries that offer rebates or where grid electricity suppliers allow households to sell excess electricity back to the grid. (Obeng, et al., 2008; Findley, 2010; Baurzhan & Jenkins, 2016).

Tam, *et al.* (2017) pointed out that some European countries are leading the way in the production of solar PV systems. Solar energy markets are increasing rapidly across the world, and solar power is now economically competitive with traditional energy sources in many states of the United States

(US), including California, Hawaii, and Minnesota. In addition, the solar industry is an established incubator for job growth across the country (EERE, 2019). Solar jobs have risen by almost 160% since 2010, which is nine times the national average rate of employment growth in the last five years. There are more than 242 000 solar employees in the US. US solar power installations have risen 35-fold to an estimated 62.5GW since 2008. This is enough to fuel the equivalent of 12 million typical American homes. Since the beginning of 2014, the average cost of solar PV panels has decreased by almost 50% (EERE, 2019). China has more solar power than any other nation in the world and is home to many major solar farms, including the biggest in the Tengger Desert in the world. China being the largest investor in clean energy in the world, wants to continue with significant increase in the proportion of renewable energy in its energy mix (World Economic Forum, 2019).

South Africa is in a transition towards renewable energy and most parts of the country have sufficient solar radiation to enable households to rely on solar systems (Ismail & Khembo, 2015; Labordena, et al., 2017). The success of off-grid households means installing energy storage systems alongside the solar PV systems. The complete solar PV system consists of a PV module, a rechargeable battery, a charge controller and an inverter (DMRE, 2020). The solar PV system is a fixed installation whose PV module is mounted in an open space on a roof or terrace that is exposed to sunlight, while the charge controller, inverter, and battery are held in a sheltered position within the building. The rechargeable battery stores energy and meets demand whenever there is a generation shortfall (Rahman, et al., 2014)

The South African government developed the Solar Energy Technology Roadmap (SETRM) to prepare a detailed guideline for the implementation of green technologies for local development of solar energy technologies (DMRE, 2020). This will create production resources and capacity, create jobs, and encourage the growth of the local industry. The draft road map estimated that 40GW of solar PV and 30GW of CSP can be generated in South Africa by 2050. South African Solar Thermal Technology Roadmap (SA-STTRM) is dedicated to solar thermal technology, focusing on the development of solar water heating and space heating, and cooling in the residential, commercial, and industrial sectors. The SA-STTRM predicts that 4GW of solar water heaters can be installed in the country by 2050 (Azimoh, et al., 2015; Jain & Jain, 2017).

The initial cost associated with solar and storage system is relatively high for most South African households (Labordena, et al., 2017). The production of the materials used in solar PV cells involves the consumption of a significant amount of energy and the use of polluting chemicals such as cyanide and sulphuric acid (Michaelides, 2012). The manufacturing of a silicon-based solar cell consumes energy that is equivalent to the energy the cell will provide in approximately 4 years (Michaelides, 2012). The high initial cost of the solar system has been noted as the major determinant to households' adoption of the solar system (Findley, 2010; Michaelides, 2012; Baurzhan & Jenkins, 2016; Palm, 2018). However, integrating all types of solar power offers and taking advantage of loans, grants, and rebates offered by governments can reduce the high solar costs (Rahman, et al., 2013). The pollutants from solar panel production are being reduced as technology changes (Eskom, 2017; DMRE, 2020). Solar has been shown to be effective in most populated areas of the world. The disposal of old solar panels is an environmental aspect that has not been highly considered (Findley, 2010). However, recycling of old solar components is being researched by scientists and big businesses (Findley, 2010).

South Africa has invested in solar home solutions such as the solar water heaters (SWHs) which was a central component of the government policy aimed at bringing development to the households (DOE, 2018). Some of the solar projects in Limpopo include the Limpopo Green Economy Plan-Biomass and Solar, and CSP, PV panels, cell phone chargers and small electrical solar appliances production (DOE, 2016). Projects for rural off-grid electrification have been pioneered, including the Solar Home Systems (SHS) initiative, which offers basic lighting power to homes, monochrome television sets, radio and cell phone charging. The project started in 2001, and more than 96 000 SHS had been completed by 2015 (Jain & Jain, 2017). The success of solar power use is seen in the water-pumping projects through the rural water-provision and sanitation program (DMRE, 2020). There are currently more than thirty operational solar power plants that feed the Eskom grid. Some of the big projects include Boshoff Solar Park, Jasper Power Company, Khathu Solar Energy Facility, Letsatsi Power Company, Lesedi Power Company, Sishen Solar Facility, Solar Capital De Aar, to mention a few (DMRE, 2020).

2.2.2.3. Solar Water Heaters

Water-heating accounts for one third to half of the energy intake of the average household. In South Africa, this is primarily achieved with electricity, which is the most common energy carrier employed. Removing this expenditure may lead to substantial increases in the disposable income of the lower-income group. The equivalent of a large coal-fired power station (2 000MW) is used to supply hot tap water to the domestic sector alone (DME, 2011). After the start of the accelerated domestic electrification program by grid extension, there has been a huge distortion of the national load curve, with the early evening load peak rising significantly (DMRE, 2019). There are economic advantages for homeowners to reduce their energy bills offered by SWHs. Expensive generation capacity to resolve demand peaks will be avoided and the implementation of new baseload capacity will be delayed by this implementation (DEA, 2013). Additionally, the country benefits in elimination of GHG emissions and the release of scarce resources for other urgent needs (DMRE, 2020).

SWHs collect light from the sun, uses the energy to heat the water and store the hot water (DMRE, 2020). An SWH has collector and storage components. Collectors are $2m^2$ per 150litres tank, with copper tubing, copper, or aluminium plates, painted black for maximum heat absorption. These tubes are insulated underneath and contained in a metal tray under a 4mm hail resistant glass. Bigger collectors capture more solar energy (Ratshomo & Nembahe, 2018). The SWHs may be direct or indirect system (DMRE, 2020). In a direct system, the collector and the storage components are connected, the water is heated directly, and the system must be freeze-resistant otherwise cannot be used in frost areas. The indirect system is naturally freeze-resistant and anti-freeze fluid is heated up in the collector, rises into a sheath around the storage tank to heat the water inside (Ledger, 2017). The SWHs systems have been used widely in townships like Soweto and Alexandra in Gauteng (Ratshomo & Nembahe, 2018). SWHs economic benefits to households are minimal due to the limited capacity of SWHs for productive and thermal use (Lemarie, 2011; Azimoh, et al., 2015). Household owners that received the SWHs from the government have raised several complaints about the quality of the systems; in most cases, they have reported leakages. There is also a perception by the public that the SWHs program is a waste of funds (Azimoh, et al., 2015).

The SWH has a panel with a tank mounted on the roof and often an element, ensuring that hot water is available whenever needed. SWHs can be used in industrial, commercial and residential settings. In 2009, the DOE initiated a SWH initiative to equip 1 million homes with SWH by the end of 2015. The program had installed only 417 135 units by 2016. In addition to the target of 1 million SWHs, the country envisaged an additional 4 million SWHs to be built by 2030 (DMRE, 2019). The original program was operated by Eskom and aimed at private and commercial installations already fitted with geysers and electricity, with the goal of reducing the demand for electrical geysers on the grid. The incentive used was a subsidy on the purchase price of installed SWHs, based on the reduction of peak demand and energy achieved (Ratshomo & Nembahe, 2018). The short-term insurance industry has launched another scheme to replace collapsed electric geysers with the SWH system. The social program roll-out of low-pressure heaters was carried out by municipalities, funded by Eskom, with full subsidies. Eskom ceased to be active in the program and formally handed it over to the DOE in May 2015, as its main business was the production and distribution of electricity, not SWHs (DMRE, 2019).

The IPP Office was instructed by the Minister of DOE to assist the DOE in the procurement and implementation of the "repair and replace" portion of the National Solar Water Heater Programme (NSWHP). The Sol Plaatje Local Municipality in the Northern Cape Province was pre-selected for the National Solar Water Heating Repair/Replace (NSWHRR) pilot programme (Ratshomo & Nembahe, 2018). The SWHs incentives were lost due to abrupt changes in government policies. Various challenges faced by the SWH program have resulted in the halting of the program, and job losses. The

DOE produced 87 000 SWH units, but none of which were installed (Ratshomo & Nembahe, 2018). No budget was allocated to SWH in the 2018/19 financial year. The SWH market has struggled to a point of no-operation (DMRE, 2020). These are projects that should be promoted to assist homes with their electricity bills and reduce the demand load on the national electricity utility. Under different strategies and policies, the programs can be implemented further in rural areas such as Limpopo and benefit rural households.

2.2.2.4. Eskom's Renewables

Eskom continues to produce electricity using mainly coal but also investing in various renewable projects. Eskom's current renewables activities are Sere Wind Farm, solar PV at Eskom sites and CSP demo plant. Sere Wind Farm was commissioned in 2013 in Western Cape and is made up of 50 wind turbines of 2MW each i.e., making it a 100MW wind farm (Eskom, 2017).

Eskom has six solar PV sites currently operating with an installed capacity of 2 500kilowatts (kW). The PV sites are located at Lethabo power station in the Free State, Kendal power station in Mpumalanga, Sunilaws in East London, Eskom's offices in Rosherville (Johannesburg) and two at head office Megawatt Park in Johannesburg - one the carports and one on the rooftop (Eskom, 2017). Kendal has a fixed-axis tilted at 20 degrees, single-axis tracking at Lethabo is installed, while Megawatt Park has fixed axis PV panels for car parks and dual-axis tracking concentrating PV (Gross, 2012).

The CSP demo plant will have a 100MW central receiver with molten salt as a heat transfer fluid. The generation of electricity from the sun to distribution lines is demonstrated in Figure 2-10 (Gross, 2012). Other specifications of the demo plant include:

- Up to 9 hours of storage
- Two tank storage systems with molten salt.
- Dry-cooling system.
- The plant will operate for at least 25 years.

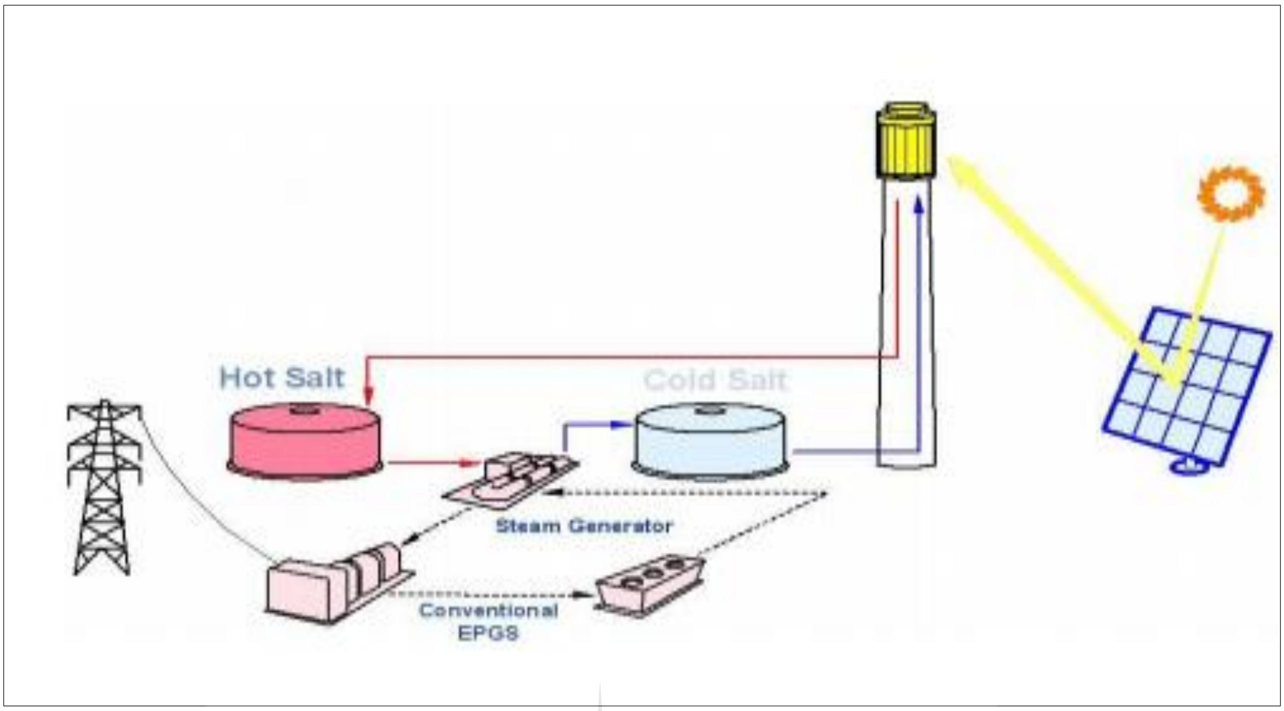

Figure 2.10: Eskom CSP demo plant (Gross, 2012)

Open Cycle Gas Turbine (OCGT) technology was introduced by Eskom in 2007 to cater for the winter peaks. OCGT can be fuelled by either liquid fuel (diesel or kerosene) or natural gas (Eskom, 2014). Air is drawn from the atmosphere by a compressor and compressed through several compressor stages. The compressed air is mixed with fuel pumped into a combustion chamber. Ignition of the fuel/air mixture creates hot high-velocity gas. This gas flows through the turbine that turns a shaft connected to the rotor of the generator. The generator rotor rotates inside the stator to generate electricity (Eskom, 2014). The hot high-velocity gas used to turn the turbines is exhausted into the atmosphere. Ankerlig and Gourikwa powers stations are Eskom's own OCGT stations with a total capacity of 1 338MW and 746MW respectively (Eskom, 2014).

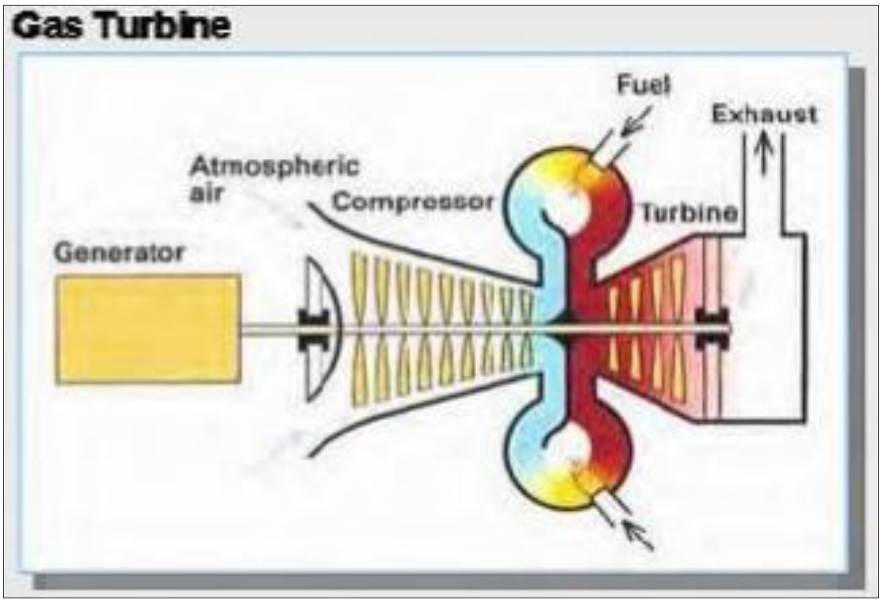

Figure 2.11: Energy transfer in gas turbines (Eskom, 2014)

2.3. Energy status quo in rural areas

The development of the economy depends on energy services; thus, it is crucial for households to have access to affordable, safe, and reliable energy (Kaygusuz, 2011; Bouzarovski & Petrova, 2015; IEA, 2015). There is still a very wide difference between urban and rural use of energy, including energy structure, the quantity of energy consumption, patterns of usage and end-user devices (Wu, et al., 2017). Rural households rely on multiple fuels to meet all their energy needs (Ado & Darazo, 2016; Han, et al., 2018). As such, rural households use traditional biofuels (Table 2-3) due to reasons such as not having access to electricity, not affording electricity, purchasing electrical appliances and/or powering the electrical appliances for daily use (Zhang & Koji, 2012; van der Kroon, et al., 2013; Ado & Darazo, 2016; Ifegbesan, et al., 2016). Households' access to electricity in developing countries is associated with better health care, increased learning rates, and increased economic participation (StatsSA, 2019; Bede-Ojimadu & Orisakwe, 2020). Most South African households that were connected to electricity have been disconnected due to the inability to pay electricity bills (Du Toit, 2014; Israel-Akinbo, et al., 2018; Kambule, 2018). Due to the availability and affordability of firewood and animal dung to most South African rural households, these fuels are the most dominant in such dwellings (Semenya & Machete, 2019).

Table 2.3: Comparison of the use of different fuels in five villages of Bushbuckridge (Limpopo) between 1991 and 2002 (Madubansi & Shackleton, 2006)

	Year	Athol	O'boom	Rolle	Welvd	Xanthia	Mean
Paraffin	1991	94	92	96	97	89	94
	2002	70	55	58	60	52	59
Candles	1991	82	73	67	82	75	76
	2002	92	94	90	96	94	93
Gas	1991	11	13	23	13	10	14
	2002	13	0	3	4	4	5
Dry-cell batteries	1991	86	78	92	91	83	86
	2002	65	12	25	31	26	32
Lead-acid batteries	1991	6	7	16	9	6	9
	2002	34	0	1	3	0	8
Charcoal	1991	21	39	19	22	22	25
	2002	31	33	25	21	29	28
Coal	1991	3	18	12	9	0	8
	2002	0	0	0	0	0	0
Crop wastes	1991	21	39	19	22	22	25
	2002	31	33	25	21	29	28
Dung	1991	6	40	0	4	4	11
	2002	6	6	0	0	0	2
Electricity	1991	0	< 1	< 1	0	0	< 1
	2002	4	98	88	98	95	77
		PV panels					
Bought wood	1991	1	68	34	19	15	27
	2002	8	63	48	20	16	31
Collected wood	1991	99	96	96	99	93	97
	2002	100	88	89	96	96	94
Mean number of energy sources per household	1991	3.9	3.8	4.3	4.4	4.0	4.1
	2002	5.1	4.1	4.1	4.7	4.1	4.4
Simpson's diversity index	1991	5.5	9.0	6.6	6.1	5.8	6.6
	2002	6.7	6.5	6.5	6.0	6.0	6.8

Table 2.4: Fuels used in various parts of the world (Semenya and Machete, 2019)

Study area	Fuel type						
	Firewood	*Electricity*	*Dung*	*Biogas*	*LPG*	*Charcoal*	*Kerosene*
China: Rural and urban	1		1	1			1
South Africa: Rural (Vhembe District,)	1	1					
Pakistan: Rural (Punjab, Sindh & Khyber-Pakhtunkhwa)	1	1			1		
Nigeria: Rural (Taraba state)	1						1
Saudi Arabia: Rural and urban	1	1					
Sudan: Rural and urban	1	1					1
Kenya: Urban (Othaya, Thuti Sub-location)	1	1		1			1
Nigeria: Urban and rural	1	1		1	1	1	1
Nigeria: (Kano Metropolis)	1				1		1
India: rural	1	1	1		1		1
Tanzania: Rural (Kilimanjaro)	1	1			1	1	1
Nigeria: Urban (Enugu state)	1						1
Nigeria	1	1			1		1
United states of America: Urban		1			1		1
Latin America: Urban and rural		1			1		
Britain: Urban		1			1		
Colombian regions	1				1		1
Western Pamirs, Tajikistan: Rural (Ishkashim district)	1		1			1	
Ghana: Urban							1
Zimbabwe: Rural (Chiwundura communal area)	1						
Southern Africa: Rural and urban (Angola, Lesotho, Malawi, Namibia, Swaziland, Zambia and Zimbabwe)	1	1			1	1	
Nigeria: Rural	1	1			1	1	1
South Asia: Urban and rural (Bhutan)	1	1			1		1
Northern Cameroon: Rural and urban (North and far north regions)	1	1					1
Nigeria: Urban (Bauchi Metropolis)	1				1	1	1
Malawi: Rural areas (Domasi and Milepa)	1						
South Africa: Rural (Ga-Dikgale, Limpopo province)	1	1					
Total	23	17	3	3	14	6	17

Figure 2.12 shows the energy transition observed in Bushbuckridge in 2002 (Madubansi and Shackleton, 2006). The solid lines show the transition done by most households, and the dashed lines show the transition done by very few households. It is evident that transitioning to electricity for cooking has been considered by only a few households. The transition to solar power was also limited to a few households.

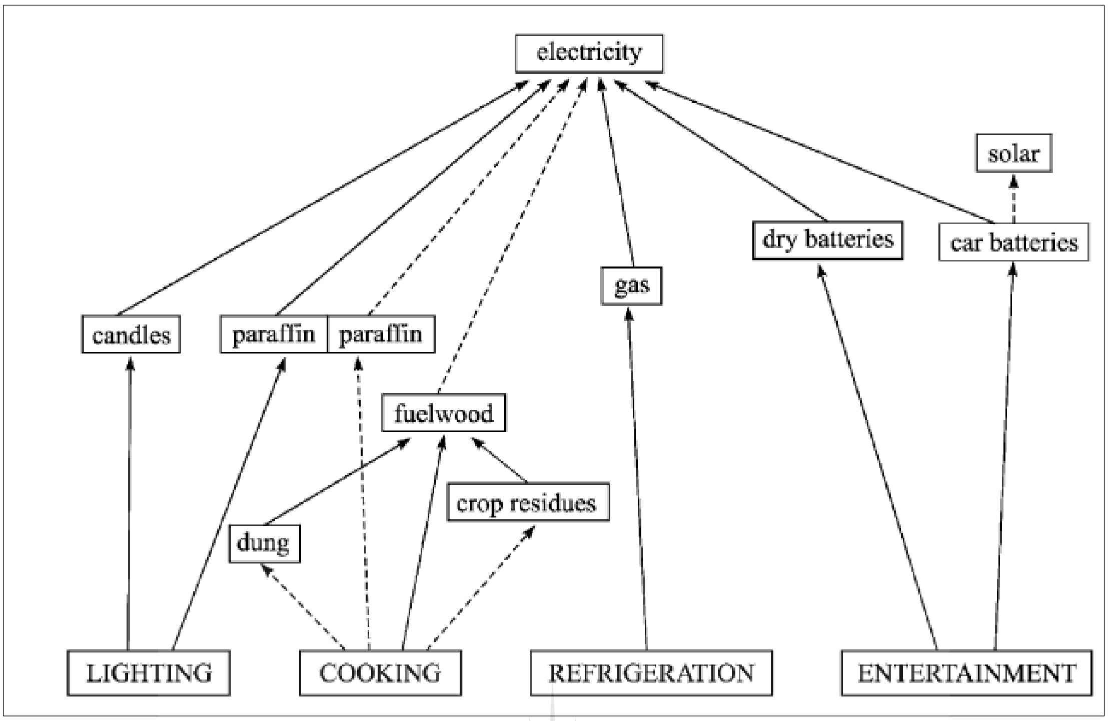

Figure 2.12: An energy web showing energy transition in the Buschbuckridge district (Madubansi & Shackleton, 2006)

StatsSA recorded usage of firewood by 41.5% of Limpopo households, compared to 10.9% of the national households (StatsSA, 2019). Figure 2-13 shows the fuels used for cooking per South African province (StatsSA, 2019), which shows Limpopo to be the leading wood using province. The extensive use of firewood in both electrified and non-electrified rural households of South Africa is shown in Figure 2-14, which shows 40% of the electrified households using firewood as one of their fuels (DOE, 2009). A similar firewood usage trend has been noted in some urban settlements in the Eastern Cape by (Shackleton, et al., 2017).

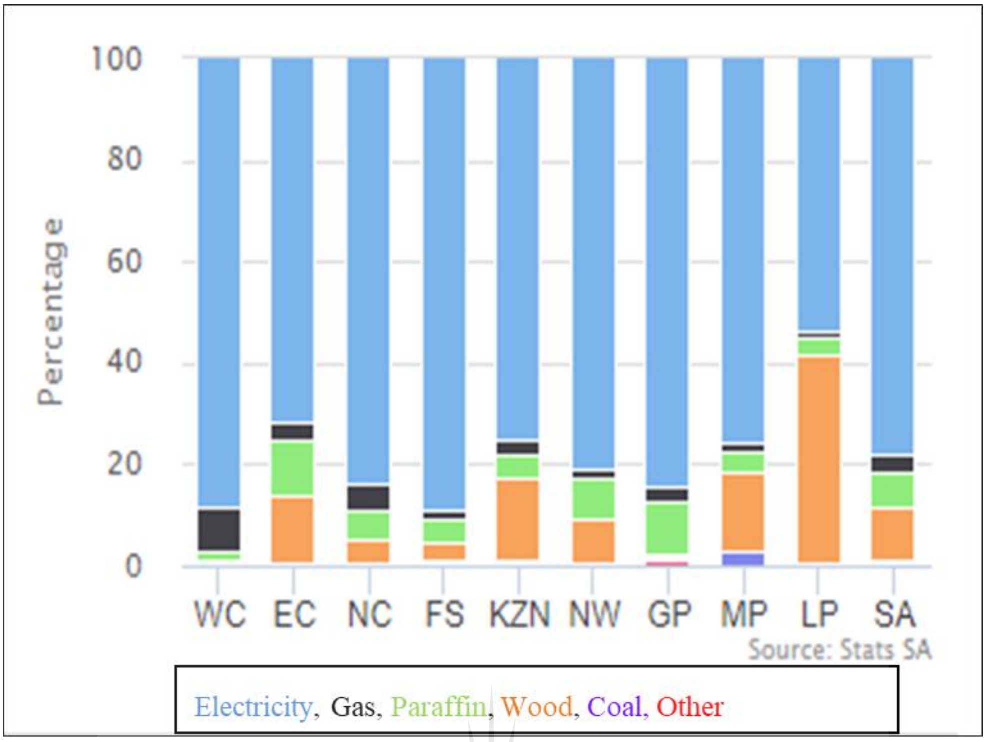

Figure 2.13: Energy used for cooking per South African Province (StatsSA, 2019)

Table 2-5 shows the fuel types used in different income level households in South Africa. Electricity is the most used fuel for all energy functions identified, in high to medium-income households, and the least used in low-income households (Sole & Wagner, 2018). This table suggests that there is a link between the type of fuel used and the household income level. The relationship is that the lower the income level, the more primitive and traditional fuels are used.

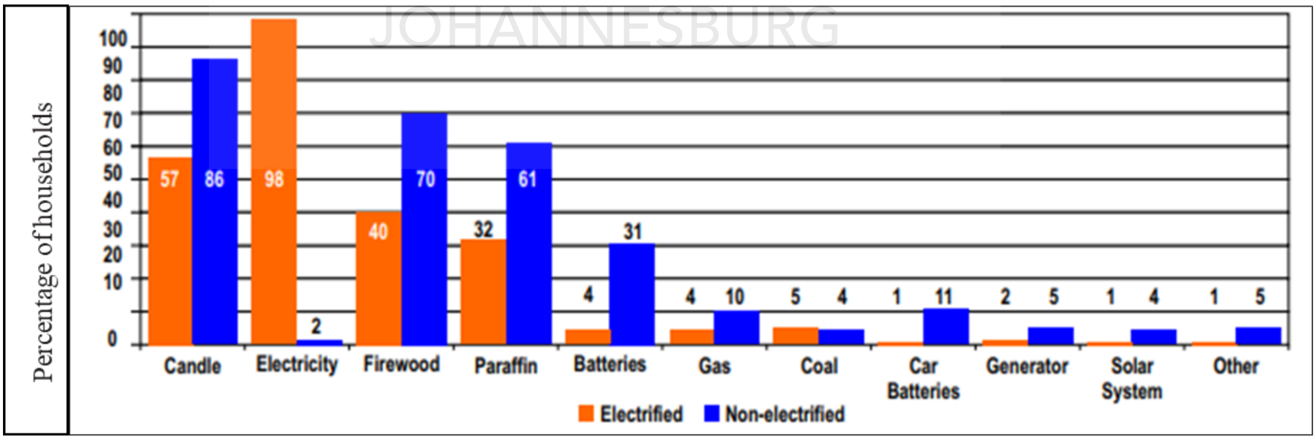

Figure 2.14: Fuel usage in rural households of South Africa (DOE, 2009)

Table 2.5: Fuels used for various energy needs depending on household income level (Sole & Wagner, 2018)

	High – mid income households with electricity	Low income households with electricity (formal & informal)	Low income households without electricity
Lighting	Use electric lightbulbs e.g. incandescent, LED	Use electric lightbulbs – low penetration of energy efficient lightbulbs, paraffin lamp or candles	Use candles, paraffin lamps
Cooking	Mostly use electrical appliances; hot plates, microwaves, ovens. A small percentage use gas cook stoves.	Combine electric appliances with paraffin, gas, wood and coal appliances	Mostly use paraffin and wood appliances with coal, gas sometimes used when available
Water heating	Mostly either use electric or solar water geysers	With installation of SWH these are used or they use electric stoves or kettles	Generally use cooking stoves for heating water
Space heating	Most households have ceilings but also use either electrical or gas heaters	Generally use electrical appliances or they use paraffin heaters or coal/wood mbawula	Generally they do not use anything any fuels otherwise they use paraffin stoves/ heaters, wood/ coal mbawula

Madubansi & Shackleton (2006) argued that firewood and paraffin were fuel choices for thermal applications in 2002. Most households used a combination of electricity and candles in 2002, and households tended to only use candles for back-up during electricity failure or when they were low on funds to purchase pre-paid electricity. According to Makonese (2017), 66% of households in sub-Saharan Africa relied on biomass fuels for cooking. This pattern is in line with the findings of Uhunamure (2017), that more than 60% of the Thulamela local municipality residents also depend on firewood for cooking and heating, despite having electricity connection.

2.3.1. Energy poverty

Energy poverty is the state of energy whereby households are unable to access energy services for less than 10-15% of the total household income, thus resorting to using unsafe, unreliable, and multiple unhealthy fuels (SEA, 2014; Ouedraogo, 2017; Kambule, 2018). A study conducted on 45 cities globally showed that people started moving away from wood at shockingly low incomes, between $12 and $30 per person per month. Nevertheless, where firewood is cheap and readily available, individuals continued with its use even with income of up to $100 per person per month. Around the year 2010, the use of modern fuels, including electricity and LPG, intensified with income of about $40-50 per person per month (International Agency for Research on Cancer (IARC), 2010; Hou, *et al.*, 2017). Households spend 4% and 10% of their total income on non-renewables and biomass, respectively (Alam, et al., 2018).

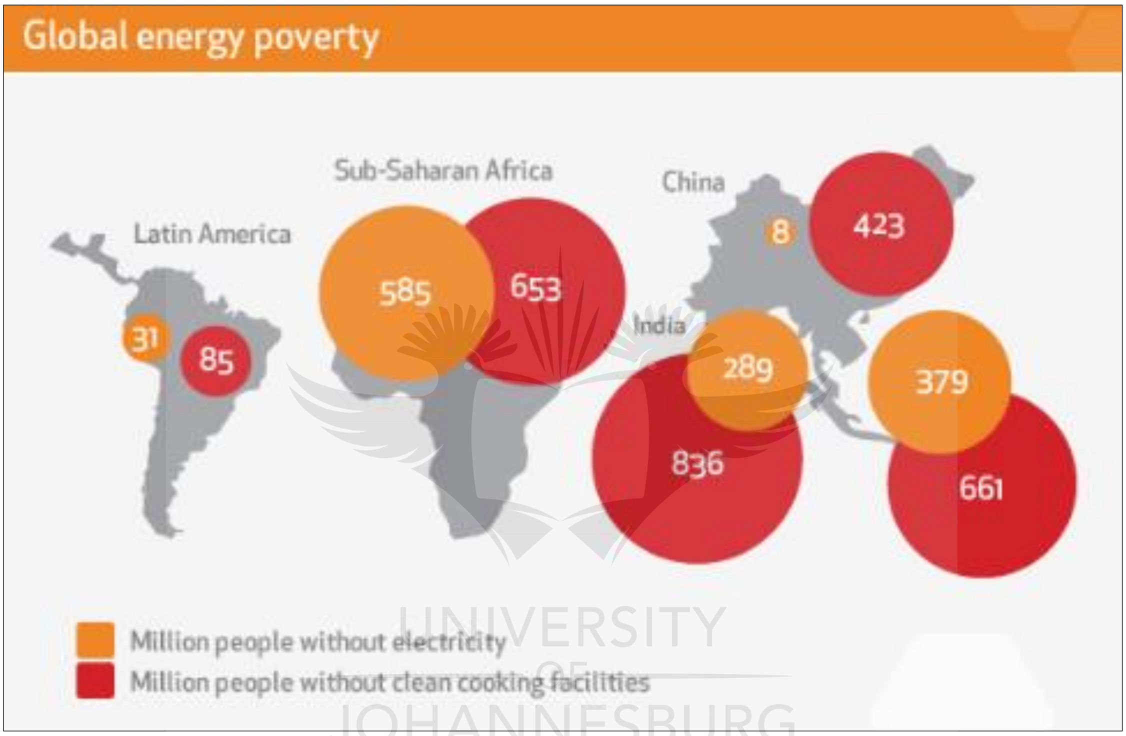

Figure 2.15: Global energy poverty (Creutzfeldt, et al., 2018)

Figure 2.15 shows the global energy poverty as it was in 2017, where 1.3 billion people did not have electricity and 2.6 billion people did not have clean cooking facilities (Creutzfeldt, et al., 2018; IEA, 2018). Sub-Saharan Africa accounted for half the people living in energy poverty, with 585 million people being without electricity in 2017 (Worldbank, 2019). IEA (2015) estimated that 2.6 billion people will still be without access to clean cooking facilities and 1 billion people without access to electricity by 2030.

The White Energy Paper in South Africa stated that "*energy security for low-income households can help reduce poverty, increase livelihoods and improve living standards*" (DOE, 1998-Section 2.4.1). South African households that experience energy poverty more are those in informal settlements, shacks, and remote rural areas (DOE, 2009; SEA, 2014). On average, South African households spend

14% of their total household income on basic energy needs (DOE, 2016). Households with lower income levels spend more than 10% of the household income on electricity as opposed to households with higher income levels, which spend 2-3% of the household income on electricity (SEA, 2014; Ismail & Khembo, 2015). Energy-related behaviour survey done by DOE in 2012 revealed that households with lower income level can spend twice as much (27% of the total monthly household income) on energy as opposed to those with higher income level (6% of the total monthly household income) (DOE, 2012; Israel-Akinbo, et al., 2018). This phenomenon is considered as energy poverty (SEA, 2014) and more than 47% of South African households were confirmed to be energy poor according to DOE (2012).

Poor health of residents, mostly children, and women, is the most hazardous effect of energy poverty (Hou, et al., 2017). Energy poverty is a significantly urgent issue in rural areas that needs to be prioritised, especially in developing countries (Bouzarovski & Petrova, 2015; Wu, et al., 2017). According to Kambule (2018), energy poverty can be alleviated by increasing household income, regulating electricity prices accordingly, as well as improving domestic energy efficiency.

2.3.2. Traditional biomass fuels

Traditional biomass energy refers to the combustion of firewood, coal, leaves, animal residue, agricultural residue, and household waste to meet energy needs (Ren21, 2004; Arku & Brauer, 2018). Rural households harvest these fuels from the local bushes, meanwhile, in the urban areas, the fuels are purchased from local markets (IARC, 2010). In rural areas with livestock, the residents can use biodigesters to turn dung and human waste into biogas for heating and cooking purposes (Eskom, 2017).

The World Energy Outlook reported the highest number of traditional fuels users to be in Sub-Saharan Africa and South Asia, with over 58% of the Pakistan population using conventional biomass for cooking (World Energy Outlook, 2008; IEA, 2015). In 2018, the WHO 2016 reported that more than 2.9 billion families worldwide were still using solid fuels for cooking and heating, such as animal dung, coal, plant waste and wood. Furthermore, the WHO (2018), revealed that in sub-Saharan Africa, solid fuel is used by 95% of the population. Virtually all rural households in Africa use biomass fuels. Though some Latin American extremely poor countries such as Haiti, have fuel consumption trends close to those seen in Africa, many other countries are moving to modern cooking fuels such as kerosene and LPG (IARC, 2010; IEA, 2018). In Asia, rural areas still rely on biomass energy, but many urban areas are increasingly transitioning to modern fuels. Overall, approximately 60% of households in Asia report using solid fuels, mainly in the form of biomass (Han, et al., 2018).

Given these trends, it is therefore expected that the use of solid fuels and in particular, biomass fuels will persist for several years to come.

A study by Alam *et al.* (2018) on household-level energy consumption in Bangladesh revealed the following:

i. Biomass fuels are consumed more than non-renewables every month.
ii. Firewood is used mostly for cooking and is the highest emitter of CO_2.
iii. Households with the highest income consume more non-renewables.
iv. There is a linear relationship between the household's income, the level of education, and the use of convenient energy fuels (Alam *et al.* 2018).

In China and some coal-producing regions of India and South Africa, coal is used as a cooking and heating fuel, often in conjunction with other biomass fuels (IARC, 2010). The coal may undergo a complex technique, such as mixing into a uniform mixture with binders to minimize sulphur and particulate emissions or simply processed by hand, to form coal cakes or balls and eventually sun-dried. Thereafter the coal is formed into briquettes designed to burn in special stoves effectively and cleanly (Eskom, 2019).

Firewood has been indicated as the most dominant fuel in many rural households in several countries globally, including China, Saudi Arabia, Kenya, Sudan, Nigeria, and South Africa (Abebwa, 2007; Cai & Jiang, 2008; De Arruda, 2016; Alternative Technology Association (ATA), 2018; Semenya & Machete, 2019; Bede-Ojimadu & Orisakwe, 2020). The largest proportion of households using mainly polluting fuels for cooking was in Africa, South East Asia, and the Western Pacific region (WHO, 2019).

In South African rural households, particularly those in the Limpopo province, the use of firewood is prevalent (DOE, 2009; Uhunamure, 2017; Ateba & Prinsloo, 2018). Uhunamure (2017) also indicated the use of firewood for both cooking and space heating (Figure 2-16). Likewise, Semenya & Machete (2019) noted that more than 90% of the surveyed Senwabarwana rural households in Limpopo preferred using firewood over electricity or dung. The firewood preference is due to its multi-functional characteristics, in that the fuel can be used for cooking, space heating as well as water heating, simultaneously (Figure 2-16a and Figure 2-17). Firewood also has social meaning beyond the utilitarian or service type relationship that electricity, LPG and paraffin have (Scottish Power plc, 2003). Traditionally, household members gather around fires during cooking time or to heat themselves up, which serve as family-time (Makonese, 2017).

Candles are used for lighting by the majority of non-electrified households in South Africa (Ateba & Prinsloo, 2018; Ratshomo & Nembahe, 2018). Candles are easily available from tuck shops and general dealers within the communities. In 2003, about 87% of South African households reported using candles at a monthly average cost of R19 ($1.26) (Scottish Power plc, 2003). The LPG lanterns and paraffin lanterns provide alternatives to candles (Choudhuri & Desai, 2020). The use of traditional biomass in households has negative impacts on the livelihoods of the users (Section 2.3.3). As a result of such implications, modern fuels have been introduced in most rural households.

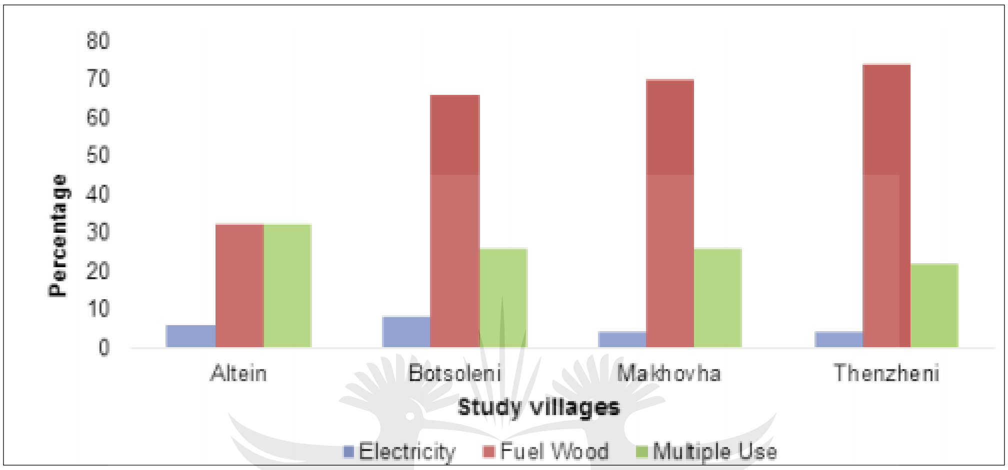

Figure 2.16: Percentage distribution of the energy used for cooking in four villages of Thulamela municipality in Limpopo (Uhunamure, 2017)

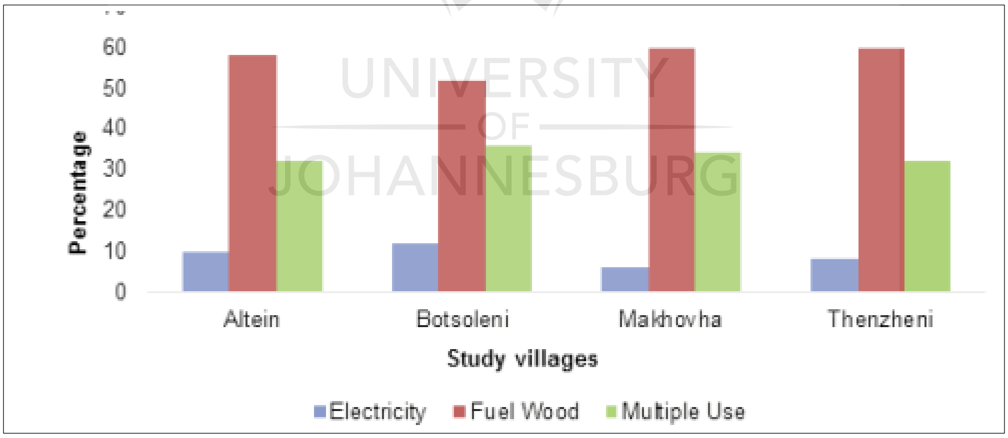

Figure 2.17: Percentage distribution of the energy used for heating in four villages of Thulamela municipality in Limpopo (Uhunamure, 2017)

2.3.3. Modern energy technologies

Modern fuels such as paraffin, natural gas, batteries, generators, LPG, and electricity are used in conjunction with traditional biomass fuels, mainly for their convenience and improved benefits. In most rural households the modern fuels do not replace the solid fuels, instead, they just form part of the households' energy mix (Baiyeghuni & Hassan, 2014; Ateba & Prinsloo, 2018). The energy transition in households from solid fuels to modern fuels, or from conventional stoves to more efficient and cleaner-burning stoves has been highly successful through energy sector reform or indigenous advanced technology in some countries, meanwhile, they have been very poor or non-existent in other countries (Alam, et al., 2018). For instance, to increase productivity and clean up the rural energy structure, the Chinese government has invested plenty of resources, such as the implementation of mini-hydro power plants, the construction of biogas, and the production and dissemination of biomass gasification plants (Wu, et al., 2017). Further, as a result of LPG programmes and clean air policies, over 450 million individuals in India and China have gained access to clean cooking since 2010 (World Economic Forum, 2019).

A common alternative cooking fuel previously used in rural households is paraffin, however, its use is limited and mainly a secondary source in most households. Paraffin stoves are used for cooking, water heating, space heating, and in some cases lighting. The fuel is hazardous in that it can be accidentally drunk by kids; spilled paraffin can result in an unplanned fire; paraffin stoves can burn children or even the user, as well as the house; or cause indoor air pollution resulting in upper-respiratory-tract infections (Lloyd, 2014; Ateba & Prinsloo, 2018). A study by Lloyd (2014), revealed that 88% of the paraffin stoves users considered it as dirty, expensive, unsafe, and made them cough. Until recently, paraffin was the most widely used modern or commercial fuel in all non-electrified rural areas in South Africa (Scottish Power plc, 2003; Howells & Alfstada, 2005). This was because paraffin could be purchased in varying unit sizes, was widely available, and its compatible appliances are both cheap and readily available. In 2003 when a litre of paraffin was an average of R3 ($0.2), an average of R70 ($4.64) was spent on paraffin per household, recorded in approximately 89% of the rural South African households (Scottish Power plc, 2003). At the retail price of an average of R13 ($0.86) per litre of paraffin in 2020, the households would be spending approximately R303 ($20.0) on paraffin monthly. However, due to a shift in households' fuel preference and technology advances, households use less paraffin monthly and thus spend way less than in the previous years.

Dry cell batteries are primarily used for powering radios, although other applications such as Hi-Fi, tape recorders, torches and clocks have been documented. About 54% of South African households indicated an average monthly expense of dry-cell batteries to be R30 ($2.0) in 2003 (Scottish Power plc, 2003; DEA, 2014). Car batteries (lead-acid) use in households was popular about 15 years ago and were used mainly for powering televisions, radios and Hi-fis. None of these activities can be considered essential, thus most rural households did not even own the batteries. Most households used their batteries for powering televisions (DEA, 2014). Car battery systems for households are often seen as a precursor for solar PV and subsequently grid electricity (Scottish Power plc, 2003; DEA, 2014). Around the year 2003, close to 40% of South African households using car batteries were spending between R20 ($1.32) and R30 ($2.0) monthly on recharging their batteries (Scottish Power plc, 2003). Currently, the use of batteries has been mostly substituted with electricity (Ateba & Prinsloo, 2018).

Generators’ functionality has evolved over the years and is commonly used for phone charging, lighting, radio, television, construction appliances, borehole for water pumping, and sewing clothes. An average of R70 ($4.6) to R300 ($19.85) monthly expense on generator fuel was recorded amongst South African generators users in 2003 (Scottish Power plc, 2003; Heinz, 2014). Generators have enabled many small enterprises to thrive without grid-electricity connection over the years and have gained popularity as a stand-by option in case of power cuts. However, it is not surprising, given the costs associated with the purchase and use (purchasing fuel) of small generators, that few households have generators. The modern diesel generator has proved to be an extremely flexible and durable way of generating moderate quantities of electricity.

There are however some significant disadvantages of diesel generators. For instance, the fuel can be exceedingly costly, or entirely unavailable. An estimation of the energy cost of a diesel generator in Africa indicates that among other problems, the cost was as high as $3.00/kWh in 2014 due to the difficulties of transporting the fuel (Heinz, 2014). Maintenance, particularly where spare parts can be unavailable, is non-trivial. Generators are often noisy, extremely polluting, and have poor overall efficiency. The Non-government Organization (NGO) Migrations Development in Morocco has helped electrify nearly 100 villages via diesel-based mini-grids in a remote mountainous region. On a fee-for-service basis, the local operators offer electricity to a village cooperative. To own, maintain and fund the electrical systems, the NGO helps the villagers create an association. This association raises about 40 % of the cost of capital and another 10-20 % of the cost for direct labour and supplies, the remainder is obtained from the European Union (EU) grant (FAO, 2003). In order to minimize costs and optimize benefits, bulk purchases are used, and all households must be connected. Least cost and competitive tariffs and requirements for services are negotiated (Food and Agriculture Organization (FAO), 2003). Less than 5% of South African households own and utilise generators (StatsSA, 2019).

LPG is an easy to handle, clean-burning fuel that is well suited for cooking. Other uses include water heating, ironing, and refrigeration. The advantages of LPG refrigeration include food preservation and opportunities for small enterprises (Scottish Power plc, 2003). Studies in South Africa have shown a growth in the use of modern non-electric fuels for refrigeration. Scottish Power plc (2003) recorded the use of LPG in non-electrified South African households to be 12% in 2003, which was lower than other developing countries with economies like South Africa.

Africa had almost 600 million people without access to electricity in 2019 (Figure 2.19), with the number expected to increase (Worldbank, 2019; The World Bank, 2020). 2020 values are estimates, which have been affected by global pandemic Corona virus disease (COVID)-19. The x-axis represents the year, and y-axis the number of million people without electricity. The increase in electrification rate since 1994, the improved economic activity, and inclusive economic participation has enabled previously disadvantaged households to include electricity in their energy mix (Kambule, 2018). In 2012, approximately 1.45 million South African households did not have access to electricity, while another 578 005 households (4%) accessed electricity informally or illegally (Kolver, 2013; DOE, 2018). Of the 4% without formal access to electricity, 73.1% were connected to an informal source that was paid for by the household, while 11.7% used illegal connections (Kolver, 2013). Stats SA (2011) recorded that there was no access to grid electricity for 33.5% of households in formal rural areas and 17.3% of households in tribal rural areas in 2010.

South Asia	2018	91.6
Sub-Saharan Africa	2018	47.7
Sub-Saharan Africa (excluding high income)	2018	47.6
High income	2018	100.0
Low & middle income	2018	87.6
Low income	2018	41.9
Lower middle income	2018	86.3
Middle income	2018	92.8
Upper middle income	2018	99.4

Figure 2.18: Households electrification rate (%) in South Asia and sub-Saharan regions in 2018 (The World Bank, 2020)

Figure 2-19 presents the number of people in Africa without electricity from the year 2000 to 2020. The number increased to a peak of more than 600 million people between 2010 and 2015, declined until 2018/9 and started increasing again. It is projected that the African population without electricity will continue to increase beyond 2020 (WorldBank, 2019).

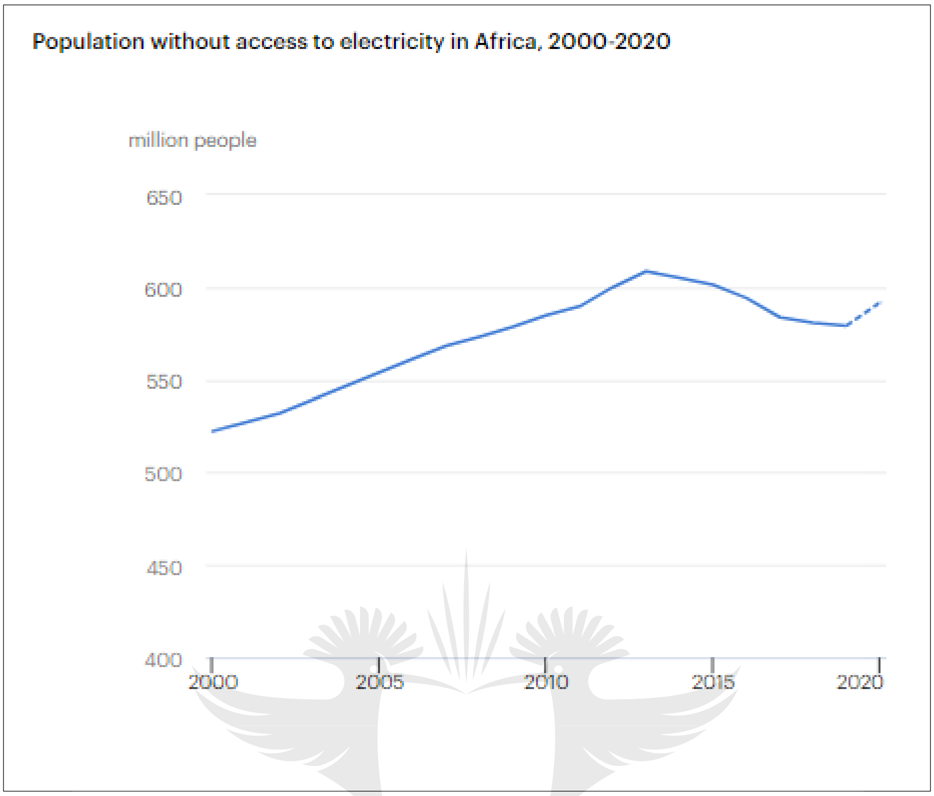

Figure 2.19: African population without access to electricity (Worldbank, 2019)

Electricity is used to fuel simple equipment such as televisions, lights, refrigerators, and water pumps (Ateba & Prinsloo, 2018). A small percentage of households (<20%) use electricity for space heating through electric heaters (Ismail & Khembo, 2015; Uhunamure, 2017). Rural households report the use of electricity to be dominantly for lighting and cooling purposes in summer (Ateba & Prinsloo, 2018). The use of electricity in South African rural households for cooking, water heating and space heating was recorded to be less than 40% in recent years (Uhunamure, 2017; Semenya & Machete, 2019; The World Bank, 2020). However, the use of electricity for lighting was as high as 98% of the households (DOE, 2018; StatsSA, 2019). Despite having access to electricity, households are not using electricity for most of their energy needs, as one would expect. The factors influencing the fuel choice are discussed in section 2.3.7.

Electricity generation has a negative impact on the environment (Section 2.3.6). Due to the impact of coal power stations on the environment and health of the nearby residents, alternative renewable energy technologies are explored. The country has moved from relying entirely on coal for electricity generation to other sources such as nuclear, hydroelectricity, solar, wind, pump storage, biomass and biogas (DMRE, 2019; Eskom, 2020). To preserve natural resources, protect the environment and reduce dependency on traditional grid electricity, renewable energy sources are thus considered essential.

2.3.4. Renewable energy technologies

There is a wide variety of off-grid electricity generation techniques for use in rural households, mostly offered by renewable energy technologies. Renewable energy technologies used in rural areas range from solar PV, small-hydro, thermoelectric power generation, biogas and wind (Azimoh, et al., 2015; Ahmad & Imran, 2018; DMRE, 2020). The extent to which any of these technologies are used depends on the cost, the effectiveness, government rebates, and available resources to support the technology, such as sufficient sunlight for PV or wind. The energy technologies can be employed as stand-alone systems or in a micro-grid system to power rural households (Heinz, 2014; Chauhan & Saini, 2015; Esposito, 2018).

Biomass (for direct combustion) uses agricultural and forestry sources or special energy crops specifically grown for energy purposes. Many methods for converting biomass into energy services have been created, representing the variety of final uses and the nature of the resource (Eskom, 2017). In general, the efficiency of the conversion of biomass to usable energy in these applications is between 5 and 15%. This compares with modern industrial processes using anaerobic fermentation to produce biogas or direct combustion in furnaces for the production of either direct heat or steam for the supply of turbines for the generation of electricity, which have conversion efficiencies of more than 20% and up to 30% (FAO, 2003).

Wet waste, such as farm slurry, green crops, night soil, agricultural residues, and some industrial effluent streams, such as sugar, beer and food production and processing, can be processed through anaerobic digestion. This creates biogas rich in methane that can be extracted and combusted. Anaerobic reactors are commonly used for the processing of methane-rich biogas from manure and crop residues (Biogas Consulting SA, 2020). Mixed methanogen bacterial are characterised by a given optimum temperature. The bacteria transform up to 90% of the feedstock energy content into biogas, containing around 55% methane, which is a readily available source of energy for lighting and cooking (FAO, 2003). The residual sludge is non-toxic and odourless and can provide good fertilizer as it retains much of its nitrogen and other nutrients. Anaerobic digesters of different designs have been commonly used in China and India. Rural initiatives have promoted biogas plants as suitable candidates for village usage due to their advantages in energy and fertilizer production as well as increased health benefits by substituting for inefficient use of wood. In 2003, there were as many as 5 million small-scale digesters used in China and India (Wang, et al., 2020).

Fushan Collective Farm in Hangzhou, China, consists of 280 families raising chickens, pigs and fish, as well as growing rice and tea. The farm had two anaerobic digesters constructed at the end of the 1990s: a $200m^3$ digester receives waste from 30 000 chickens and a larger $500m^3$ digester receive slurry from 8 500 pigs (FAO, 2003). The digesters contain biogas, liquid effluents and solid sludge. Biogas is used as cooking fuel in farmworkers' homes, for leaf drying in tea processing plants and for space heating in chicken coops. Liquid effluent is used as a feed supplement for pigs (only chicken digester) and fish, and as a crop fertilizer for rice and tomato development. Sludge is also used as an intermittent feed for fish and organic fertilizer. The capital costs were compensated for by each family's initial investment in the farm and by a small bank loan. The cost of the supply of biogas to each house and cooking stove was included in the initial investment. Biogas replaced the use of straw and rice husks as cooking fuel and improved local air quality (FAO, 2003). BiogasSA has two simple small scale digester designs: the in-situ cast concrete Puxin digester and the functional and cost-efficient Do it yourself (DIY) Biobag Digester Pack (Biogas Consulting SA, 2020). In rural South African households, small scale digesters are used mainly for cooking and water heating. There are various small biodigesters projects in The Willows village, Marulaneng municipality, and some villages in Sekhukhune district.

Residential wind power can take various forms; if the conditions for a larger turbine are correct, a home might theoretically get most or all of its energy from the wind. The wind power can also be used as a complementary source in households and for other purposes. For instance, ranchers and farmers can use wind power for lighting or space heating, charging batteries and water pumping (Jain & Jain, 2017; Ygrene, 2018). While large-scale wind turbine deployment has advanced significantly over the last few decades, wind power has not had a significant impact on rural and remote electrification, especially in areas affected by poverty. Simple technology has been around for a long time, as small-scale wind turbines are widely used to supply recreational marine vessels with electricity and some high-end off-grid homes (Heinz, 2014; Ygrene, 2018). The relative uncertainty, high-cost and intermittent generation have limited the use of wind power in rural electrification. A typical 10kW wind turbine installation cost as much as $55 000 in 2014, which for these economically vulnerable regions is simply too high (Heinz, 2014). Due to the wind turbine size required, and the cost associated to power a home, as well as lack of wind sources (the amount of wind blowing) available in the Limpopo province of South Africa, wind power is not a viable and practical solution for such households. In fact, most households only benefit from wind power as a micro-grid setup or in a hybrid system where the turbines are placed away from the houses.

Thermoelectric generation from a temperature difference is not a usually known means of supplying electricity, except for advanced applications such as waste heat recovery and wireless sensing in harsh environments. Small capacity and generally low thermodynamic performance are limited to the current state of the art thermoelectric generation (Heinz, 2014). The application of technology has some undeniable advantages. Usually, even the most remote and undeveloped areas still have a heat source used for cooking and providing survival warmth. There is inevitably a large amount of waste fuel, whether this is a wood fire, kerosene stove or another heat source. With off-the-shelf thermo-electric modules, this waste heat can be used to produce a small amount of electricity (Heinz, 2014). This may be adequate to charge a mobile device or lamp, but the scale is likely to remain largely inadequate without considerable advances in thermoelectric technology. In addition, common materials such as lead, tellurium and bismuth used for thermoelectric modules are toxic (Heinz, 2014).

The old waterpower technology has been made more useful for off-grid, small-scale electrical power by recent innovations. These systems range from approximately 100W to 10kW in size. The smallest systems rely on simple paddle wheels, such as adapted car alternators or reverse-driven pumps, mated to off the shelf generators. They can only need immersion in a quickly flowing stream, or probably a simple pipe with a controlled descent to produce additional water pressure (Heinz, 2014; Eskom, 2017). The amount of power generated by these generators is adequate to recharge small battery-powered electronic devices such as cell phones and Light Emitting Diode (LED) lanterns.

A small dam (often constructed of locally available materials) is needed for larger micro-hydro plants and can provide power for appliances such as refrigerators and desktop computers (Heinz, 2014). The greatest challenge with both the small and somewhat larger hydroelectric generation is their reliance on steady water flow (Eskom, 2017). Without a buffer provided by a large dam, these generators can fail during drought or dry seasons. Otherwise, they are very environmentally friendly, easy to maintain and do not need fuel. In one example, the installation cost per household for a 2.2kW device was $81 in 2014, and electricity was then supplied at an incredibly competitive cost of $0.15/kWh (Heinz, 2014; Eskom, 2017). This energy technology is however not applicable to most rural South African households due to lack of access to adequate water.

Solar PV power is an obvious alternative to provide electricity to remote and isolated areas (Azimoh, et al., 2015). Solar energy has become very affordable and available with the recent decline in the cost of solar panels (Nkoana & Jarbandhan, 2018; Mashele, 2019). The maximum solar irradiated power is greater than $1kW/m^2$, and while cheap solar panels have a modest efficiency (≈12%), this solid-state technology can still be used to harvest considerable electricity (Heinz, 2014). A simple solar system with direct current will last over 20 years (DMRE, 2020). For small installations, an estimation of the cost of solar photovoltaic power based on average performance, cost and lifetime show the cost to be $0.25/kWh, while a separate calculation showed that the cost was $1.09/kWh in 2014 (Heinz, 2014). Solar energy is only usable during the day of course, and even bad weather will make the device almost useless. With energy storage, this issue can be prevented, but this is difficult and expensive (Heinz, 2014; Eskom, 2017).

Micro-finance for rural households using solar PV systems has been employed in various locations to help communities come together and reduce the cost of electricity through crowd funding. Bangladesh, Morocco, Philippines, and Sahel region are some of the areas that implemented this system (Alam, et al., 2018). A non-profit organisation, named Grameen Shakti (GS), founded by Grameen Bank in Bangladesh specializes in rural development micro-credit. GS seeks to supply rural households with renewable energy technology and build local jobs. The organization is providing 24-month leasing financing to customers beginning with PV systems to spread out the initial cost of equipment. The GS estimated that one million Bangladesh households without electricity would be able to afford these systems (FAO, 2003). At the same time, GS is educating a local retailer-technical network to provide on-going maintenance and customer service.

In a Dutch-funded project in the Philippines, the Development Bank of the Philippines agreed to finance PV solar home systems, but only village cooperatives, to escape high costs of servicing several individual small loans. The Bank rents out the systems and thus retains the PV panels as collateral. If the cooperative must return the PV panel due to defaults of payment, the dealer who provided the device must agree to buy it back (FAO, 2003). Another financial safety net is offered by the cooperative's own finances, which may typically carry out payments for a while to people who have financial difficulties.

Solar PV drinking water pumps and community systems have been installed in remote areas of nine countries in the North African Sahel region. The village associations in this region pay for the key production of the project-water. These fees include the wages of the villager who runs the system plus day-to-day maintenance, annual maintenance and a deposit fund that is raised for the eventual repair of the system (FAO, 2003). The SHS and SWHs projects are some of the solar projects for South African rural households (Azimoh, et al., 2015). Due to the cost associated with purchasing solar PV and the installation, most rural households do not have solar PV. Fewer than 5% of South African rural households have solar lighting (DMRE, 2020).

Rapid technological developments have moved renewable energy sources from a costly option to an economically feasible alternative. The International Renewable Energy Agency (IREA) recently reported that the cost of renewable energy sources such as wind and solar will continue to decline significantly and will begin to be cheaper than fossil fuels by 2020 (TechCentral, 2019). Though solar projects are still relatively expensive in comparison to geothermal sources, onshore wind, and hydropower, the cost of solar plants has dropped by more than 70% since 2010 and continues to decline (DMRE, 2020). The lower prices of solar systems due to technical advancements and increased competition in the global solar industry have also resulted in a significant drop in the capital cost of building a small-scale or household solar system in South Africa (TechCentral, 2019; DMRE, 2020). TechCentral (2019), reported a complete off-grid solar PV system for a typical South African household to have declined from R300 000 ($19 854.4) a decade ago to between R150 000 ($9 927.2) and R200 000 ($13 236.27).

BUSINESSTECH (2019) reported the costs associated with getting off the Eskom electricity grid. One of the options mentioned was a solar system, costing between R2 000 ($132. 36) and R180 000 ($11 912.64) depending on the household size and required power. Notably, the bigger the household size, the more costly the solar PV system required becomes. The following possible systems were presented:

- One or two small solar panels and a 10-20W-powered battery which would cost between R2 000 and R5 000. This option would be able to power a few lights and a cell phone charger.
- A broad solar panel and a 120W-powered battery costing between R9 000 and R16 000. Potentially, this can power around five lights or a Television (TV), or a refrigerator.
- The 1.5kW – 3kW solar PV system, with batteries, powering 280-305W and costing more than R50 000 ($3 309. 07). This system power capacity is equivalent to a few bulbs, a TV and a refrigerator (BUSINESSTECH, 2019).

Most of these renewable energy systems are usually safe at low voltage and low power and do not require significant capital investment. The basic generation strategies, like those described in the above section, must be scaled up and synchronized into micro-grids for larger-scale power generation and distribution. A basic micro-grid's architecture is as follows: generation source, electronic load balancing, electronic power conditioning, and distribution network. Usually, micro grids are built to deliver continuous power that supports the same demand levels as a full-scale electric grid. Thus, micro-grids should be able to sustain factories and large appliances such as refrigerators, unlike most off-grid generation (Heinz, 2014; Ahmad & Imran, 2018).

Micro-grids are much more difficult and expensive than off-grid development to provide these levels of operation, costing in the region of $30 million in 2014 (Heinz, 2014). A micro-grid must have some degree of redundancy to provide reliable electricity, and not rely solely on inconsistent generation sources such as solar or wind. The generation source is often a combination of a renewable source and a diesel or gas generator, likely with a battery bank to better balance the load and power. Moreover, the electronics needed to operate micro-grids autonomously must react quickly because of the smaller number of sources and loads of generation (Heinz, 2014). However, it is worth noting that micro-grids often have the advantage that it can be relatively easy to combine two or more grids as the centralized grid expands, eventually powering the micro-grid region entirely from the main grid (Chauhan & Saini, 2015). While microgrids are a much more complete solution than an off-grid generation, they are costly, requiring specialized maintenance and are simply not feasible in many circumstances (Heinz, 2014).

2.3.5. Alternative fuels for cooking

Alternative energy-efficient, cleaner and safer fuels have been emerging. Modern or clean cooking fuels are defined as those used in stoves with a high energy density, high combustion efficiency and high heat transfer efficiency with adequate heat control characteristics (Chauhan & Saini, 2015; Baek, et al., 2020). Biogas and LPG are typical alternative modern gaseous cooking fuels, while ethanol and kerosene are the key liquid alternatives for cooking (Stockholm Environment Institute (SEI), 2011). One of the most popular modern cooking technologies is improved cook stoves. Improved cooking stoves are cooking stoves that allow users to cook with fire in a much more efficient and healthier environment (Mapako, 2012; UOA, 2020). Improved stoves have been rolled out in various countries from as early as 1995 to minimize the smoke released by an open fire when cooking. The improved stoves have several benefits such as those mentioned below (Bede-Ojimadu & Orisakwe, 2020; UOA, 2020):

- i. The ability to burn moist wood that cannot burn in an open fire.
- ii. Keeps pots clean.
- iii. Removes smoke from the house.
- iv. Once warmed up, the stove cooks quickly (Mapako, 2012).

Improved stoves users have however revealed the shortcomings of some improved stoves as follows (Mapako, 2012):

- i. They are slow to warm up.
- ii. Their holes were too small for bigger pots, resulting in pots being too far from the firebox and thus slower cooking.
- iii. Cannot be used for quick meals that require instant heat.
- iv. The kitchen gets too hot in summer, thus cooking outside with open fire is preferred.
- v. Cannot be used for cooking needs such as brewing, which require big drums.
- vi. Requires considerable maintenance such as renewal of grates and repairing cracked tops.
- vii. Cannot be used with dung as the smell from burning the dung was too strong for inside the kitchen.

viii. They require split wood of particular size, and the wood splitting is a time-consuming process.

ix. Considered a waste of dry wood.

x. Chimneys placed close to grass thatch were risky and thus cooking outside with open fire was preferred.

Mapako (2012) discovered the shortcomings of improved stoves in Southern Africa as the limited use of stoves to just cooking, not meeting space heating needs; and the potential of the stoves overheating the kitchen during hot seasons. Similar shortcomings were noted by other researchers (Simon, 2010; Pailman, 2018; Ecozoom, 2019). Pailman (2018) analysed the perceptions and desires of users of improved biomass cooking stoves, building on the results of a small household survey conducted in South Africa, Mozambique, Malawi and Zambia. In the results, it was noted that the purchase and implementation of these stoves did not result in the overall substitution of conventional stoves by households. The factors that influenced the initial adoption of the stove, such as the cost of technology and the reduction of smoke, differed from those that influenced its continued use (Pailman, 2018). The need for improved cook stoves in South Africa is less severe than in most other African countries (Ecozoom, 2019). It can be concluded that when it comes to meeting rural household cooking needs, no one-size-fits-all approach can be applied, and thus authorities looking into mitigating the use of firewood should consider multiple solutions for different households.

No. of gas appliances	Appliance needing replacement	Solar?	Best economic decision
NEW HOMES			
N/A	N/A	Yes	Go all-electric
		No	Go all-electric *(Go all-electric OR dual-fuel in Sydney and Adelaide)*
EXISTING HOMES			
One	Any	Yes	Switch to electric
		No	Switch to electric
Two	Heating	Yes	Switch both to electric
		No	Switch both to electric
	Hot water	Yes	HOT WATER AND HEATING: **Sydney** Stay on gas *(switch both OR stay on gas outside CBD)*; **Elsewhere** Switch both to electric
			HOT WATER AND COOKING: **Queensland** Switch both to electric; **Elsewhere** Switch both OR stay on gas *(switch is better for large households)*
		No	HOT WATER AND HEATING: **Sydney** Stay on gas; **Adelaide** Switch both OR stay on gas; **Elsewhere** Switch both to electric
			HOT WATER AND COOKING: **Queensland** Switch both to electric; **Elsewhere** Switch both OR stay on gas *(switch is better for large households)*
Three	Heating	Yes or No	**Queensland** Switch all to electric; **Elsewhere** Switch heating to electric *(switch heating OR stay on gas in Sydney CBD)*
	Hot water	Yes or No	**Sydney, Adelaide, Brisbane** Stick with gas; **Elsewhere** Switch all to electric *(switch all OR stay on gas in Melbourne and for small and medium households in Dubbo and Wodonga)*

Figure 2.20: Proposed fuel choice in Australian households (ATA, 2018)

2.3.6. Impact of currently used fuels

The negative impacts of using biomass have been highlighted in several papers (Davis, 1998; van der Kroon, *et al.*, 2013; Arku & Brauer, 2018). For example, wood consumes time (Figure 2-21) and energy to gather (Dorji, 2012), which could have otherwise been used to make economic contributions (Madubansi & Shackleton, 2006; WHO, 2019). As more houses are built, the wood collection time increases due to the distance from the homes to the bush. Household members in Bushbuckridge spent at least 3 hours daily collecting firewood, with the collection time increasing with the years, as seen in Figure 2-21. Additionally, the collection of wood has potential exposure to violence and injury (WHO, 2015). The heavy loads carried, and polluted air inhaled during indoor combustion of fuelwood has negative impacts on the users' health (Weber & Sotelo Montes, 2017). Paraffin is a hazardous fuel because it may be accidentally drunk by kids; paraffin stoves can burn children or even the user, as well as the house; spilled paraffin can result in an unplanned fire; or cause indoor air pollution resulting in upper-respiratory-tract infections (Lloyd, 2014; Ateba & Prinsloo, 2018). A study by Lloyd (2014) revealed that 88% of the paraffin stoves users considered it as dirty, expensive, unsafe and made them cough.

Wood consists mainly of two polymers namely: lignin which accounts for approximately 30% and cellulose (50-70% by weight). Other biomass fuels such as grass, wheat stubble etc. contain these polymers in different proportions. Additionally, small quantities of organic compounds (e.g., sugars, waxes, resins) of low molecular weight and inorganic salts are found in wood. Pyrolysis occurs during combustion, and the polymers split apart to create several smaller molecules (IARC, 2010). Solid fuels are difficult to burn in small simple combustion systems, such as household cooking and heating stoves, without significant emissions of contaminants. This is primarily due to the difficulty of fully pre-mixing the fuel and air during burning, which is easily achieved with liquid and gaseous fuels. As a result, a large fraction of the fuel carbon is converted into incomplete combustion products, i.e., substances other than the ultimate full combustion product, such as CO_2 (IARC, 2010). The emitted contaminants from the combustion of solid fuels vary greatly depending on the nature of the fuel and appliance/stove used.

Depending on its volatility, each product emitted from incomplete combustion can be present in the particle phase, gas phase or both phases. Incomplete combustion products released from biomass combustion are a complex mixture of particulate and gaseous chemical species, including carbon monoxide, nitrogen dioxide and particulate matter. These products often contain a significant number of hydrocarbons that are precursors to photochemical smog and constitute ozone, aldehydes and particles (IARC, 2010). The intrinsic contaminants found in coal such as mercury, silica, sulphur, fluorine, lead and/or arsenic are not destroyed during combustion; instead, they get released into the air in their original or oxidised form. Households that use sulphur-rich coal are more exposed to sulphur dioxide emissions.

Figure 2-20 details how rural households' energy consumption affects the economy and the environment. Grass and firewood harvesting result in vegetation deterioration and thus environmental deterioration. Vegetation deterioration ultimately results in crop yield production for agricultural rural households and thus more money must be spent on buying fertilizer, which can result in loss of profit. Indoor air pollution, health risk and health expenses increase with every solid fuel used in the households (Figure 2-21).

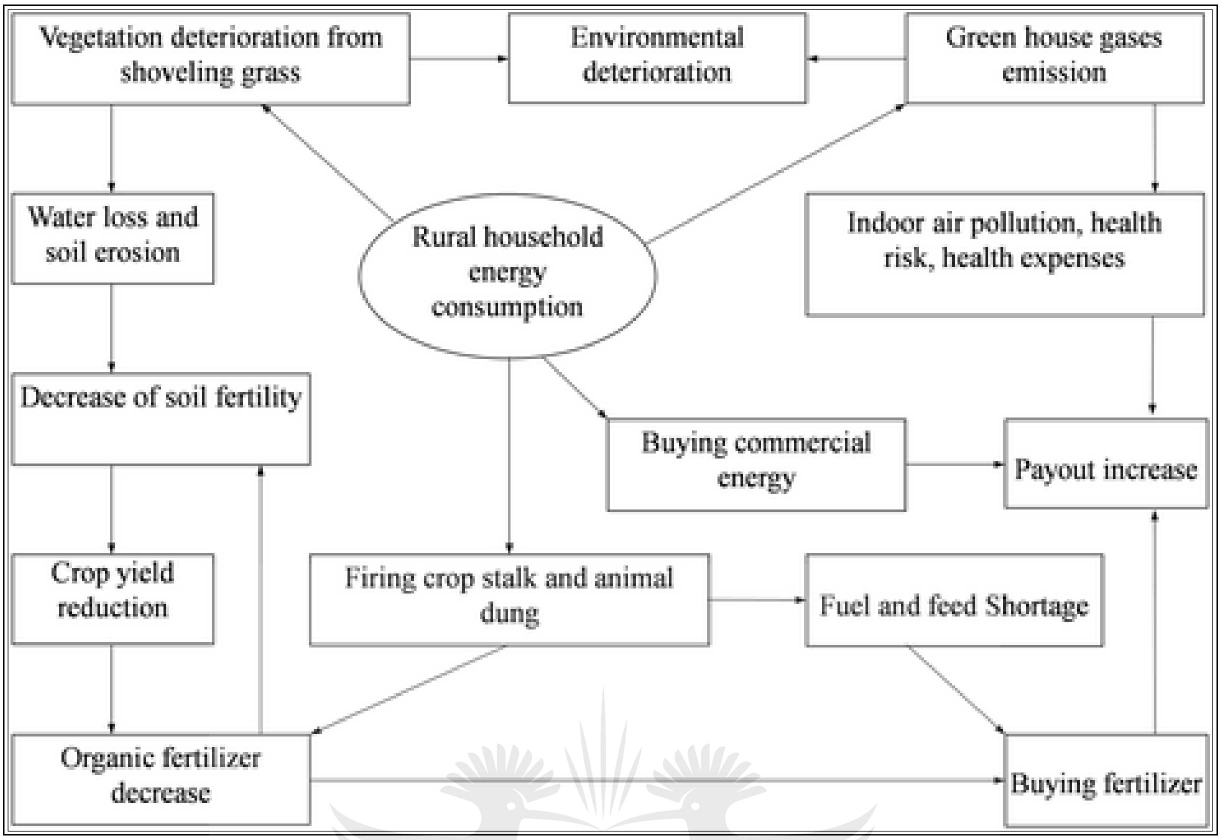

Figure 2.21: Rural households energy consumption's impact on the environment and the economy (Li, 2016)

Cooking indoors with solid fuels results in house air pollution, which is the third leading risk factor for global morbidity and mortality (WHO, 2015). The WHO (2016) reported that household air pollution contributed to 3.5 million deaths worldwide in 2010. Outdoor air pollution resulting from household air pollution caused an additional 370 000 deaths and 9.9 million disability-adjusted life years globally in 2010 (WHO, 2016). Additionally, in 2010 Pakistan recorded that there were 28 000 deaths each year and 40 million cases of an acute reparative disease that are associated with insufficient combustion of conventional fuels (Imran, 2019). Women and children, in particular, are implicated in the morbidity and mortality linked to cooking with solid fuels (Imran, 2019). Figure 2-22 shows the wood collection time in 1991 and 2002 in five villages of Bushbuckridge. The time increased from 1991 to 2002 in all five villages by approximately 20minutes, which may have been due to forests being cut down to build houses. A relationship between the use of solid fuels and an increase in blood pressure, chronic obstructive pulmonary disease, acute lower respiratory infections, odds of hypertension, lung cancer, cataract, and stillbirth and low birth weight has been revealed by Arku & Brauer (2018), and WHO (2016).

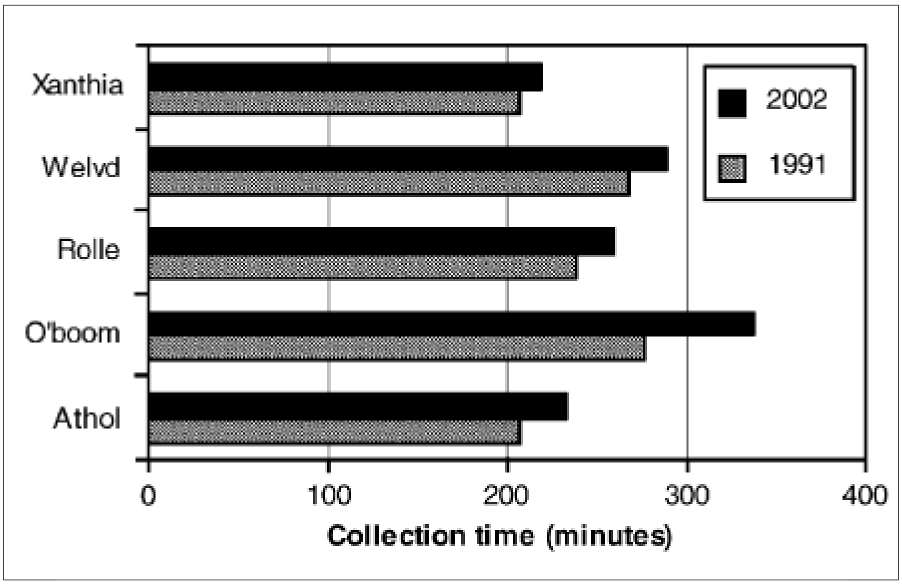

Figure 2.22: Average wood collection period per trip (in minutes) in 1991 and 2002 in five villages of Bushbuckridge

People without access to electricity are denied opportunities for health and development, such as engaging in small crafts and trades or studying, due to the requirement of adequate lighting. These people are at risk of sustaining injuries, burns, and poisoning from the use of polluting lighting fuels (Howells & Alfstada, 2005; WHO, 2018). The heavy loads carried, and polluted air inhaled during indoor combustion of fuelwood has negative impacts on the users' health (Weber and Sotelo Montes, 2017; Arku and Brauer, 2018). Using cleaner energy may reduce cardiovascular risk in rural residents (Arku & Brauer, 2018). The Global Alliance for Clean Cook stoves (Global Alliance for Clean Cookstoves (GACC)) is making efforts aimed at switching 100 million households to clean cooking stoves by 2020 (WHO, 2018). Improved stoves have the ability to minimize indoor air pollution, to burn wood or other biomass more effectively, and even to reduce average cooking times (IARC, 2010; Mapako, 2012).

Primary challenges that remain barriers to further biogas development in South Africa are the shortage of water and the lack of a generic solution. Biogas technology cannot simply be moved from one continent, country and area to another (Biogas Consulting SA, 2020). This is due to local climatic conditions and the availability and proximity of feedstock strongly influencing the nature of the digester, agitator and anaerobic technology used. Thus, extensive testing before the correct process, technology, and feedstock mix must be determined (ESI Africa, 2016; Biogas Consulting SA, 2020).

Every year, an estimated 15 million hectares of tropical forest are cleared to provide firewood for cooking and heating or small-scale farming. There is a notable contribution by traditional biomass fuels and burning of fossil fuels, to global warming. As one of the major sectors of energy consumption, the household sector contributes 21% of total CO_2 emissions, primarily due to the use of conventional fuels (Imran, 2019). Global warming is the extremely rapid rise in Earth's average surface temperature over the last century, largely due to the release of greenhouse gasses from people who burn fossil fuels (NASA, 2019). Fossil fuels such as coal, petroleum and wood will increase the amount of sulphur dioxide, carbon dioxide and nitrous oxide in our atmosphere (Tam, et al., 2017). Models project that as the world consumes ever more fossil fuels, greenhouse gas emissions will continue to increase, and Earth's average surface temperature will rise. Based on realistic emission scenarios, mean surface temperatures could rise between 2 ° C and 6 ° C by the end of the 21st century (NASA, 2019). Some of this warming will continue even if potential greenhouse gas emissions are limited since the Earth system has not yet completely adapted to the environmental improvements that we have already made (WHO, 2015).

The inefficient combustion of solid fuels contributes to global climate change (WHO, 2015). The effect of global warming is much greater than just rising temperatures. Warming modifies rainfall patterns, amplifies coastal erosion, prolongs rising seasons in some areas, melts ice caps and glaciers, and alters the range of some infectious diseases (Tam, et al., 2017). Some of these improvements are already taking place (Bonan, 2008). The development and promotion of renewable energy sources are one of the main success factors in resolving global warming issues (DOE, State of Renewable Energy in South Africa (SoRESA)).

Every kilowatt of electricity produced from coal is associated with the following emissions (Energy Information Administration (EIA), 2020; Eskom, 2020):

i. Sulphur dioxide (SO_2), which contributes to acid rain and respiratory illnesses.
ii. Nitrogen oxides (NO_x), which contribute to smog and respiratory illnesses.
iii. Particulates, which contribute to smog, haze, and respiratory illnesses and lung disease.
iv. Carbon dioxide (CO_2), which is the primary greenhouse gas produced by burning fossil fuels (coal, oil, and natural gas).
v. Mercury and other heavy metals, which have been linked to both neurological and developmental damage in humans and other animals.
vi. Fly ash and bottom ash, which are residues created when power plants burn coal.

Renewable energy has been viewed as means to mitigate climate change, reduce CO_2 emissions and contribute to the country's energy mix. Climate change is an inevitable event, which has happened before where we had ice age and global heating. CO_2 is believed to be a very dangerous and global warming constituent gas. However, a theoretical calculation has shown that without other factors, doubling the atmospheric CO_2 would result in less than 1 degree Celsius of surface heating. South Africa is believed to be the leading CO_2 emitter in Africa because of its coal mines, but these statistics do not consider sequestration and biomass burning. When considering sequestration and biomass burning, SA emits 0.051Gt/y of CO_2, which makes it 35^{th} in the world and takes it out of Africa's top 10 CO_2 emitting countries (DRC becomes first) (Ledger, 2017). It is empirical that South Africa does not base its energy technology investment solely based on global warming yet consider global warming as one of the influential factors. The negative impacts of renewable energy sources such as those indicated in Figure 2-23 should not be neglected in energy policy making. The figure indicates the number of birds killed by wind farms from REIPPP Round1 in SA (Ledger, 2017), and if such numbers are not considered, the country risk extinction of some bird species.

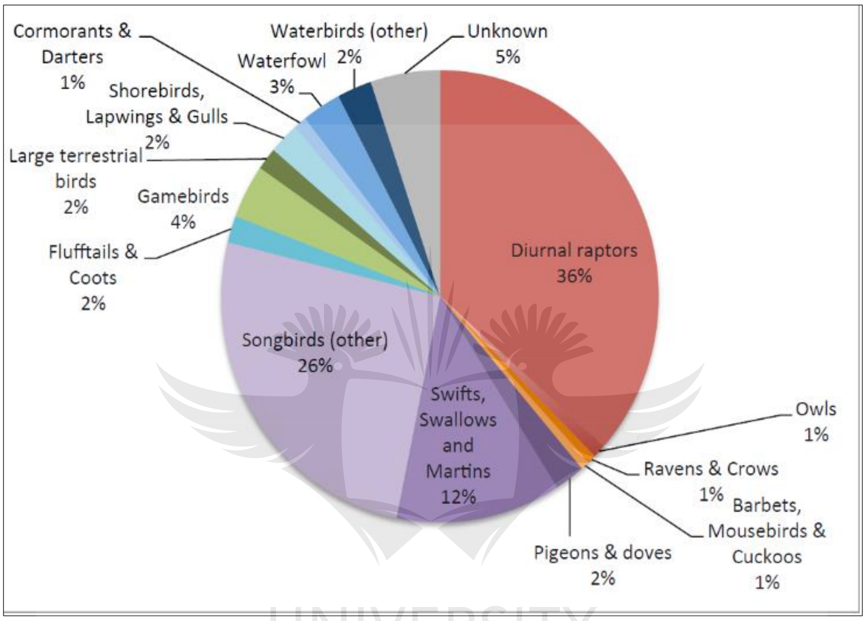

Figure 2.23: Birds killed by Wind Farms from REIPPP Round1 in SA (Ledger, 2017)

SA contributes to climate change and will suffer the impacts thereof. As an energy-intensive country and fossil-fuel-powered economy, the road to curbing climate change is a costly and long one. SA government regards climate change as one of the greatest threats to sustainable development. The Government also believe that the impact of climate change can reverse all the development progress made by the country (DOE, National Climate Change Response (NCCR), 2015). The country has made it a point that mitigation and adaptation programmes are initiated and implemented towards a low carbon economy and stabilizing climate change. The alignment of SA's emissions reductions with Africa is vital. There are major climate impacts that will be felt in Africa if not mitigated, such as injuries, food shortage, contagious diseases, deaths, malnutrition, water contamination and exposure to vector-borne diseases. The African Continent should address lobbying, leadership, knowledge and capacity building on climate change, innovation, and cooperation to enable controlling of climate change (CEI, 2016).

2.3.7. Factors influencing fuel choice

Energy transition, energy ladder and energy stacking

Household fuel choice decision-making process has been researched and two approaches were suggested, namely energy stacking and the energy ladder (Leach, 1987; Kowsari & Zerriffi, 2011; Baiyeghuni & Hassan, 2014). The energy ladder shows a process in which households move away from traditional fuels as their income increases, first to adopt intermediate fuels, and then to use modern fuels (Leach, 1987; Kowsari & Zerriffi, 2011; Muller & Yan, 2016). The energy ladder concept suggests that an increase in socio-economic status makes households to abandon primitive fuels such as firewood, agricultural waste, and animal waste (Figure 2**.24**). The concept argues that people of higher socio-economic status use only advanced fuels such as electricity, LPG and biofuels (Abebwa, 2007; Baiyeghuni & Hassan, 2014; Choudhuri & Desai, 2020). Ultimately, this means transition fuels like charcoal and kerosene are only used by households in the middle of the socio-economic ladder (Kowsari & Zerriffi, 2011; van der Kroon, *et al.*, 2013).

The energy transition process diagram (Figure 2-25) shows a linear relationship between the socio-economic status and the type of fuel used (van der Kroon, *et al.*, 2013). Davis (1998) observed evidence of energy transition in rural areas as a result of having access to electricity. The transition was largely driven by income level. The energy ladder based on socio-economic status theory is supported by a study done in China (Cai & Jiang, 2008). Advanced fuels cost more but offer benefits such as less pollution and timesaving, whereas the primitive fuels cost less to nothing, require greater labour input and more polluting (Danlami & Applanaidu, 2018). Access to electricity, however, does not guarantee a complete transition as suggested by the energy ladder theory (Baiyeghuni & Hassan, 2014; Davis, 1998).

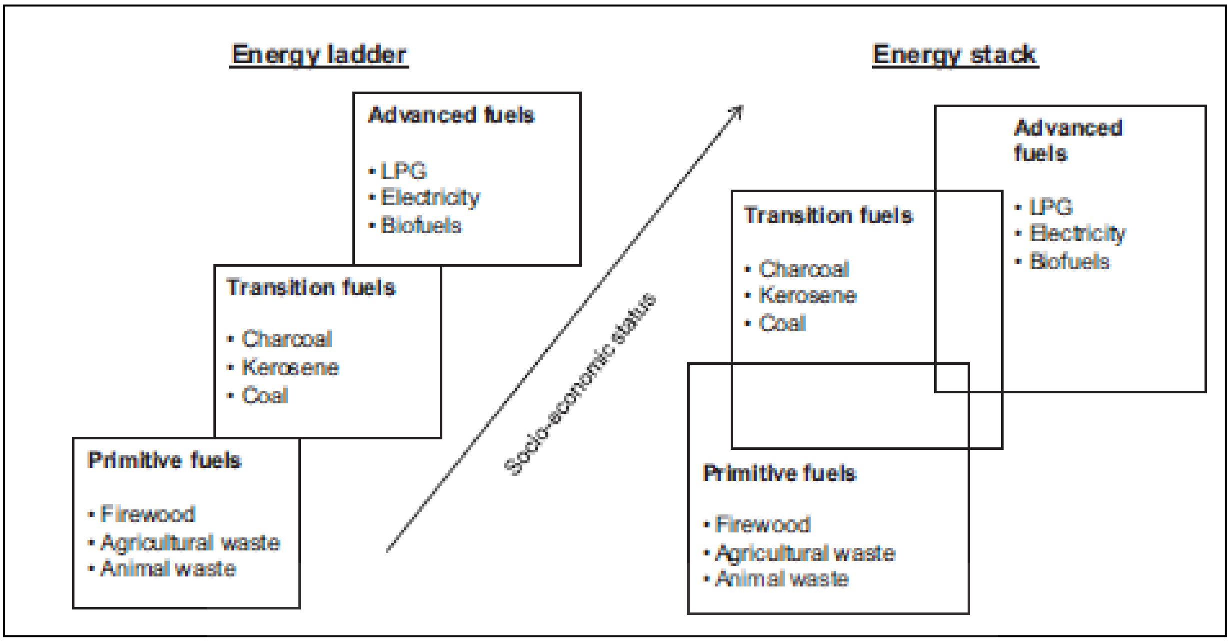

Figure 2.24: The energy ladder and stacking fuel transition process in relation to socio-economic status (van der Kroon, *et al.*, 2013)

Van der Kroon, *et al.*'s (2013) conceptual framework in Figure 2-24 defines three types of factors that affect household energy decision-making as follows:

- The context of household decision-making, including external political, institutional and business considerations.
- The external socio-cultural and natural environment such as ecology, history, climate.
- The household characteristics such as education, income and household size.

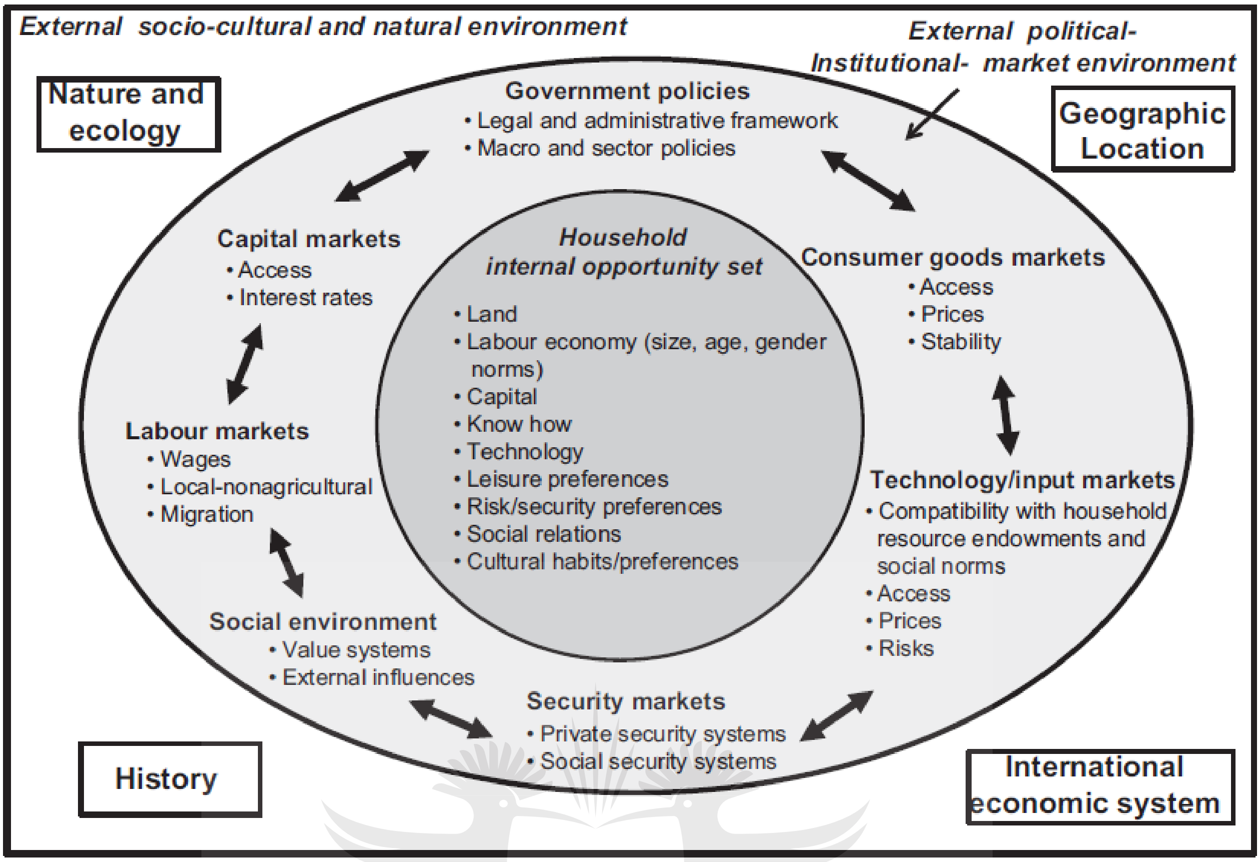

Figure 2.25: Van der Kroon, *et al.*'s (2013) conceptual framework on household fuel choice

Both figures 2-23 and 2-25 show that most households do not rely on one energy fuel and that people of the middle socio-economic status are more likely to use various fuels (van der Kroon, et al., 2013). The energy ladder is challenged by several authors who explain household fuel choice using the energy stacking concept. Energy stacking theory states that an increase in socio-economic status allows households to add more advanced fuels to their energy mix, without completely transitioning away from primitive fuels (Figure 2.**24**) (Masera & Kammen, 2000; Han, et al., 2018). Thus, the high-income earners would still consider using solid fuels, though in smaller proportions as compared to those of lower-income level (Muller & Yan, 2016).

The energy stacking process of the rural household energy transition is categorised into traditional biomass energy, traditional commercial energy, and advanced commercial energy (Han, et al., 2018). As indicated in Figure 2-25, an increase in prosperity and development does not result in a complete disregard for solid fuels, instead, some of these fuels are carried over into the energy mix with non-solid fuels. The high-income level households can afford the cleanest, convenient and safe cooking fuels such as electricity, and thus opt for that and others such as natural gas (Kowsari & Zerriffi, 2011; Hou & Liao, 2019).

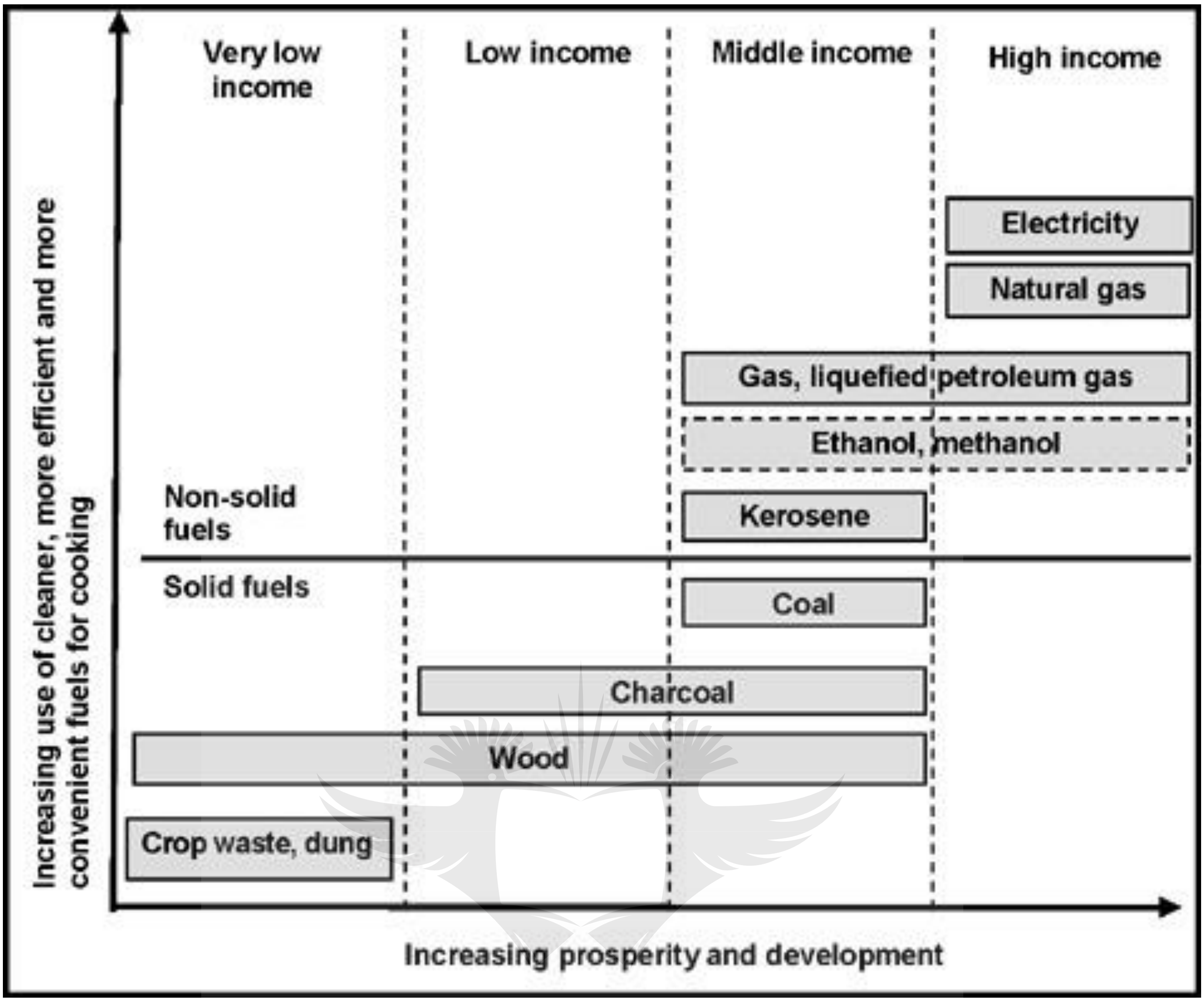

Figure 2.26: Households' transition from biomass fuels to modern fuels in relation to household income (WHO, 2006)

Figure 2-26 shows the energy profile associated with factors fuel choice in households. The factors vary from personal attributes (preference, habits, perception), household demographics (household size, income), shared factors or external conditions such as geographical setting, policies and regulations, and prices of fuels to mention a few. These factors are not independent of each other, there are interlinked one way or the other. Ultimately, these variables influence the energy fuel(s) selected, and appliances were chosen thereof.

Factors such as income, reliability of the supply channel, knowledge of technology, culture, and tradition have been noted as some of the influences of the fuel choice decision making (van der Kroon, *et al.*, 2013; Uhunamure, 2017, Semenya & Machete, 2019). The examination of household electricity usage in four African countries (Malawi, Uganda, Ethiopia, and Tanzania) by Rahut, *et al.* (2017) revealed that wealth, education, female-headed households, household position, and access to infrastructure are common determinants that influence household use of electricity as the main source of lighting. Other researchers revealed that the cooking fuel choice is affected by the place of residence, the gender of the homeowner, access to electricity, level of education, and wealth (Mensah & Adu, 2015; Makonese, et al., 2018).

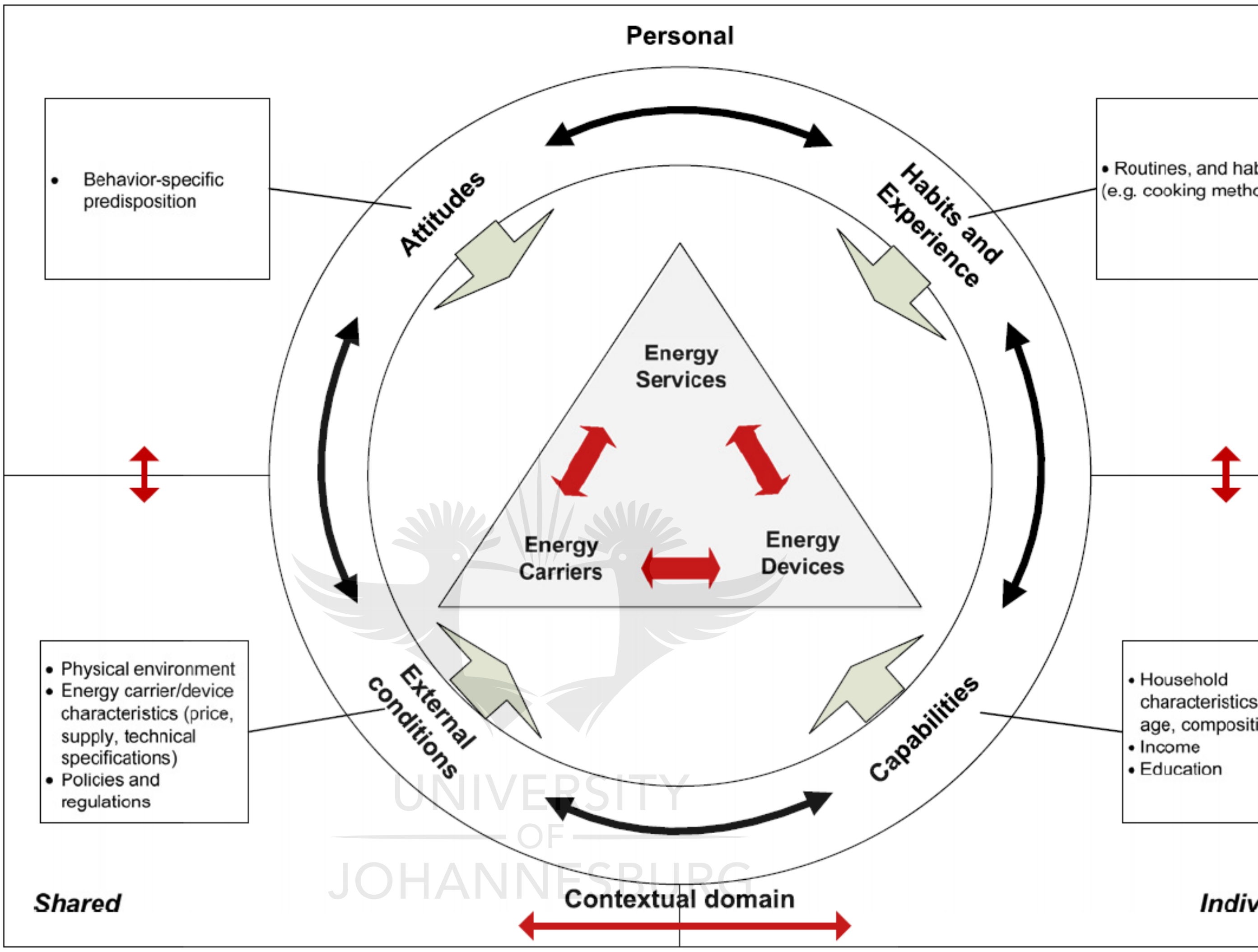

Figure 2.27: Energy profile showing factors influencing household energy use (Kowsari & Zerriffi, 2011)

Semenya and Machete (2019) identified various factors that influence the fuel choice decision-making process as seen in Table 2.4. The top 5 contributing factors in Senwabarwana are income, level of education, place of residence, household size and fuel availability. These factors are amongst the top identified factors by other researchers such as Mensah & Adu (2015), and Uhunamure (2017). Amongst the least contributing factors in Senwabarwana is frequency of cooking, safety, smoke emissions, culture/tradition and employment status. Culture/tradition has however been noted by Uhunamure (2017) as one of the major contributing factors.

An estimation of fuel expenditure and price fluctuations of household fuels in Pakistan to note the link between fuel choices to price was conducted, which enabled the implementation of cleaner fuels (Cameron, et al., 2018). Ma & Yu (2018) also discovered that household size, income, homeowner age, and information accessibility affect the decisions made regarding fuel choices in rural households. The adoption of cleaner stoves introduced to China residents was higher in households where the females had the authority to make decisions (Hou, et al., 2017). In rural Mexico firewood and traditionally made stoves are used to cook better-tasting tortillas at a rate 5 times higher than gas (Masera *et al.*, 2000). Consumers prefer mixed fuel sources for some of the reasons mentioned above (Ma & Yu, 2018). It is worth noting that some contributing factors and the extent to which those factors affect the fuel choice are only applicable to certain dwellings.

Gender

Researchers have noted a difference in household fuel choice based on the gender of the household head (Howells & Alfstada, 2005; Hou, et al., 2017; Semenya & Machete, 2019). In a study by Semenya & Machete (2019), 87% of the respondents were female and the utmost users of firewood. Women are responsible for cooking in most households, and thus mostly responsible for fuel choice selection. In cases where women earn income and make financial decisions, they chose cleaner fuels (Kohlin, et al., 2012). Choudhuri & Desai (2020) further argued that intra-household gender inequalities play an important role in shaping the household decision to invest in clean fuel, by revealing that there are a positive increase and statistically significant correlation between women that earn income and the use of cleaner fuels. Conversely, the WHO (2016) has revealed that men oversee the household budget in many societies and have more influence over selecting the fuel choice (Kohlin, et al., 2012; WHO, 2015)

Ateba & Prinsloo (2018) revealed that about 98% of the male participants used electricity for lighting as compared to just above 92% of the female participants. It was also revealed that about 37% of the female participants used electricity for cooking as opposed to over 41% of the male participants (Ateba & Prinsloo, 2018). Moreover, the use of firewood for cooking was prominent in female-headed households (30%) than less than 13% of the males (Ateba & Prinsloo, 2018). The traditional socio-economic responsibilities of (Nwaka, et al., 2020) men as financial providers and that of women as households' caretakers (Uhunamure, 2017) encourages more males to participate in economic activities than females. It is for this reason that energy choices in female-headed households are linked to limited economic opportunities that guarantee cleaner energy options. Contrary to this, Rahut *et al.* (2019) found that female-headed households in rural Pakistan are more likely to use safe and convenient sources of fuel, such as cooking with natural gas. Since the female member is responsible for the collection of fuel and cooking, the household prefers to use clean fuel when the females make household decisions. Supporting this is the positive and statistically significant correlation, showing about a 3% probability increase of grid-electricity use for lighting by women over men in Kenyan households (Baek, et al., 2020). Based on the opposing literature presented on the effect of gender, one can argue that the impact of gender on fuel choice depends on other household demographics and external factors. It is thus empirical to consider other factors when concluding on the effect of gender on household fuel choice decision making thereof.

Age

The literature shows that household heads of different ages make different fuel choices. However, the effect of age on household fuel choice remains contradictory. Some studies show that the older the household head, the higher the chances of using traditional fuels (Mekomen & Kohlin, 2009; Mensah & Adu, 2015; Semenya & Machete, 2019). Older homeowners have firewood embedded in their lifestyle and view the use of new energy technology as abandoning their culture (Mensah & Adu, 2015; Uhunamure, 2017). Rural households in China with elderly members have 0.103 lower probability of choosing clean fuels as their primary cooking fuel (Hou & Liao, 2019). On the other hand, other studies have revealed a positive statistical correlation between an increase in household head's age and the use of cleaner fuels.

Older household owners in rural Ethiopia were found to prefer modern fuels over traditional fuels (Guta, 2012). Additionally, Rahut *et al.* (2019), revealed that with one-year increase in the age of the household head in Pakistan rural households, the probability of adoption of gas for cooking increases by 0.1%. These findings may be due to younger homeowners not yet being as financially stable as the older homeowners, hence the choice to use traditional biomass fuels, which are much cheaper. Despite the two opposing views on the effect of age on fuel choice, other authors suggest that the age of the household head does not affect the fuel chosen (Israel, 2002; Abebwa, 2007). As it was discussed with the effect of gender on fuel choice, one can similarly suggest consideration of other fuel-choice-influencing factors in line with age, rather than exploring the effect of age as an independent variable.

Marital status

The results of a study on lighting fuel choice in Kenya (Baek, et al., 2020) showed a positive and statistically significant relationship for kerosene, but negative and statistically significant one for solar panel based on the marital status of the homeowner in Kenya. The study further revealed that compared to single-household heads, when the household head is married, the likelihood of selecting kerosene as the main lighting fuel increases by just below 8%. Married couples tend to have higher monthly expenses than a single household, and for some families, the high upfront cost of solar panels may not be affordable. Moreover, when there is a strong electricity demand, a solar panel offers the greatest advantage, but this is not the case for most Kenyan households (Baek, et al., 2020). The probability of using electricity increases by 0.2%, charcoal by 2.5%, kerosene by 0.07% and decreases the probability of using LPG / natural gas by 2.6% and wood for cooking purposes by 0.2% for married couples in Ghana (Karakara & Dasmani, 2019).

Due to the combined income in a home of a married couple, (if both partners earn an income) it becomes more affordable to supply the electricity for cooking services than for single households' heads (Mensah & Adu, 2015; Karakara & Dasmani, 2019). However, the opposite can be argued to be true in a case where only 1 partner of the married couple earns an income i.e., the household size will be bigger thus higher energy demand but only one source of income. This can be better explained by the results from a study by Karakara & Dasmani (2019) which states that increasing the household size by one member leads to a decrease in the likelihood of using electricity by 0.03%, LPG / natural gas by 4.4% and raises the probability of using charcoal by 4.2%, wood by 0.2% and kerosene by 0.01% for cooking purposes. In such a case, a single homeowner might be able to afford electricity better than a household with a married couple, (all other factors frozen/equal/same).

Level of education

Literature shows a significant role played by the household's level of education in fuel choice decision-making process. In most cases, the household member with the highest qualification tends to make the financial decisions for the household (Permana, et al., 2015). Uhunamure (2017) found that Thulamela local municipality residents with higher education level had an attitude of being more energy efficient, energy-conserving and environmentally considerate. The attitude was the opposite for those with lower or no education at all. An increase in the level of education attained by the household head or financial decision-maker has been noted to increase the chances of using cleaner fuels in households (Ifegbesan, et al., 2016; Uhunamure, 2017). Karakara and Dasmani (2019) argued that if the household head has at least a primary education, it raises the probability of using electricity by 0.1%, LPG / natural gas by 13.2%, kerosene by 0.01% and decreases the likelihood of using charcoal by 13% and wood by 0.3%. Similarly, in Kenyan households, studies by Baek, Jung and Kang (2020) showed that the likelihood of selecting a solar power lighting over kerosene increases by about 6, 15, and 26 %, when the household head has earned primary, secondary, and tertiary education, respectively. An educated person may be aware of the potential hazards of using traditional fuels (such as wood, charcoal, grass and animal dung) and would thus opt for modern fuels (such as electricity, renewable energy technologies and LPG). Moreover, a higher level of education increases the chances of securing a better paying job, thus availing more capital towards cleaner fuels (Karakara & Dasmani, 2019). However, other researchers have found no significant association between the level of education and fuel preferences (Semenya & Machete, 2019). Increasing awareness of alternative fuels and promoting further studies for household members can help transition households' reliance on traditional biomass fuels to modern fuels.

Household size

The number of members in a household is one of the factors influencing fuel choice. The average household size in rural households is that with 5 members (Uhunamure, 2017; Danlami & Applanaidu, 2018), with households as big as 19 members per household identified in some areas such as Senwabarwana village in Limpopo (Semenya & Machete, 2019). Bigger households have higher energy demand and thus require more capital to meet their fuel needs. Literature has found that households with more members prefer using firewood (Rao & Reddy, 2007; Pandey & Chaubal, 2011; Zhang & Koji, 2012). The results of a study in Thulamela municipality rural households showed a significant correlation between the increase in household size and the use of firewood over electricity (Uhunamure, 2017).

Karakara (2019) found that an increase in the size of the household by one member increases the probabilities for charcoal by 4.2%, wood by 0.2% and kerosene by 0.01% and leads to a reduction in the probabilities of using LPG/natural gas by 4.4%, electricity by 0.03% for cooking purposes. This association is mainly since cooking and water heating for more people requires more time and energy, thus becoming more costly. The high cost of electricity somehow forces such households to opt for the free available fuel, i.e., firewood. Semenya & Machete (2019) found that the size of Senwabarwana villages households were bigger than the minimum required household income per person and explained the use of firewood in bigger households as a result of a higher proportion of household members to household income. However, the opposite trend was found to be true in studies by Guta (2012), and Baiyegunhi & Hassan (2014), arguing that bigger households tend to choose cleaner fuels over firewood. This opposing argument may be because more household members may earn multiple income earners, thus availing more funds towards cleaner fuels. A thorough investigation is required to determine the nature and shape of the effect of household size on household fuel transition.

Place of residence

The geographic location of a household affects fuel choices. A study by Li (2016) on village differences in rural household energy consumption within the Loess hilly region of China, indicated the different fuels used in different geographic settings as detailed in Table 2-6. Three geographic settings were identified, namely: mountainous, semi-mountainous and plains along the river district. The energy needs for the identified settings were heating and cooking, and they were met by different fuels depending on the location. Kang is an integrated system for cooking, sleeping, household heating, and ventilation, used in both mountainous and semi-mountainous districts.

Table 2.6: Fuels used in different geographically set households of Loess in China (Li, 2016)

Geographic setting	Fuels used
Mountainous	Primary (straw and kangs) Auxiliary (coal, biogas, solar energy, wood, and animal manure)
Semi-Mountainous	Primary (coal, kangs and stoves) Auxiliary (straw, wood, and solar energy)
Plains (River District)	Primary (coal and stoves) Auxiliary (straw, wood, grass and solar energy)

Income level

Poverty is inextricably related to the use of biomass. Income is inarguably one of the most influential factors to households' choices; be it type of house purchased or built, furniture owned, the number of kids to have, which school children attend, fuels used, clothing, transportation (Ritonga, 1994; Tchereni, 2013; Faisal & Brew-Hammond, 2013). The average total household income in rural areas has been noted as relatively low (StatsSA, 2011). Households with lower income level can spend twice as much (27% of the total monthly household income) on energy as those with higher income level (6% of the total monthly household income) (Bouzarovski & Petrova, 2015; Kambule, 2018). Most households in developing countries use biomass energy, but there is an increasing change to modern fuels as well as a trend in the opposite direction. The transition from solid fuels is almost unavoidable when households can afford to step up the energy ladder and access to modern fuels is not a problem.

Income has been noted as the leading factor influencing households' fuel choice by several researchers (Davis, 1998; Rao & Reddy, 2007; Semenya & Machete, 2019). Households switch from firewood to coal when household incomes increase, and when firewood prices rise, they consume coal as a replacement (Karakara & Dasmani, 2019). Tchereni (2013) found a negative relationship between income and firewood share in the energy budget. Likewise, the relationship between energy use and household income levels in Ghana was examined by Faisal *et al.* (2013), and the results suggested that there is a positive relationship between charcoal or LPG and income levels, but firewood is found to be negative at all income levels. The link between income level and the fuels consumed in households is further explored by the energy ladder and energy stacking concepts discussed earlier (van der Kroon, et al., 2013; Zhang & Koji, 2012).

An increased probability in richer households was noted to be 0.1% for electricity, 42% for LPG/natural gas to cook and 40% for charcoal to cook (Karakara & Dasmani, 2019). Ateba & Prinsloo (2018) also investigated the impact of energy fuel choice determinants on sustainable energy consumption of selected South African households and noted the following patterns:

i. Townships households on average were within the lower income brackets compared with those from main town zones.
ii. Electricity for lighting was used by 94.3% of the low-income group and 95.8% of households from the high-income group.
iii. Most high-income earners used electricity for heating at 79.1% and cooking at 95.8%.
iv. Low-income earners used electricity less for heating at 71.5% and cooking at 77.6%.
v. Low-income households tend to use gas at 16.5% as an alternative cooking fuel compared with 35.2% of high-income households.
vi. High-income groups tend to use paraffin for cooking at 3% compared with low-income households at 15.2%.
vii. Low-income households used firewood and coal for cooking at 42% and 72% respectively.
viii. High-income households used coal and firewood for cooking at 4% and 5.5% respectively.
ix. Solar water heaters were used by 24.2% of the high-income households compared to 10.1% of the low-income households.

The level of income affects fuel chosen, appliances purchased and period each of the appliances is used for. Household income has repeatedly presented itself as an influential variable that co-exists with other factors influencing fuel choice, such as household size and marital status (preceding sections). Thus, one must considerably investigate all factors influencing fuel choice, individually, in relation with each other and together as a unit.

Fuel accessibility and availability

Fuel accessibility and availability were assessed as factors influencing fuel choice by previous studies. Access to electricity has been noted as one of the factors positively influencing the shift away from traditional biomass fuels (Wu, et al., 2017). Accessibility to modern fuels plays an important role in household fuel choice, and it is measured by access to electricity, households' perceptions of LPG availability, and prevalence of renewable energy technologies (Zhang & Koji, 2012; Muller & Yan, 2016). On the other hand, availability of firewood was determined based on the geographic location, the distance and time required to collect firewood, and the households' perception of firewood availability (Muller & Yan, 2016). The further away the firewood is from the households, the higher the probability of moving away from using firewood (Muller & Yan, 2016; Wu, et al., 2017). In the South African context, the geographic location effect on fuel choice is observed in rural residents of the Highveld in Mpumalanga who tend to use more coal than the rest of the rural households in the country. This choice is due to easier access to coal than firewood in the area, thus less costly. Access to renewable energy was indicated as a means for households to consider alternative and cleaner fuels over firewood. The dominance of firewood in rural households is often due to it being the only available, usable and affordable fuel in the area (IEA, 2015; Semenya & Machete, 2019). In rural communities without grid-electricity-connection, the use of firewood is inevitable as that would be the only fuel available and accessible (DOE, 2012).

Convenience

Despite the several disadvantages of firewood that have been recorded, firewood is one of the fuels that can meet multiple energy services needs simultaneously. Figure 2-27 shows how that heat distributed from a single fire can be used for cooking, water heating, and space heating (Howells & Alfstada, 2005). The flexibility of firewood to meet multiple energy needs simultaneously has been stated by some of the households studied as the reason for their choice to use firewood. Advantages of using electricity include timesaving and safety. In a household's fuel choices, accessibility to fuel plays an important role. Alternatives, which are mainly dirty fuels, are required to be used by populations without electricity (Adam, 2010; Chauhan & Saini, 2015).

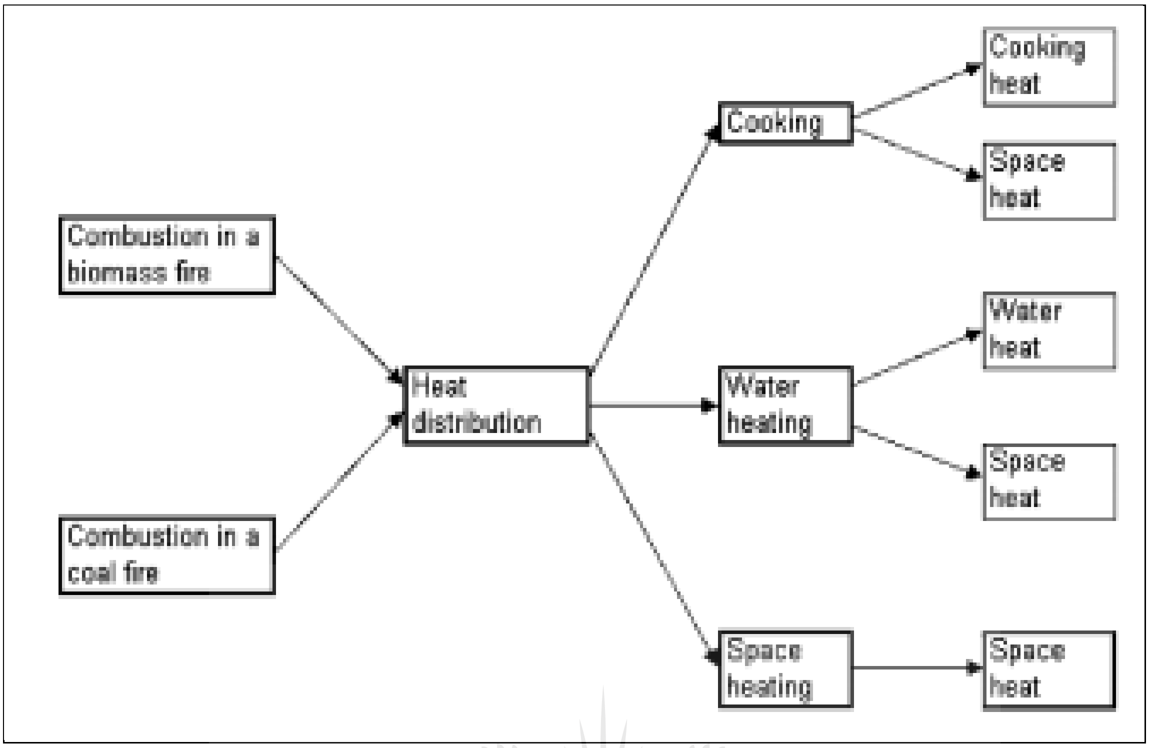

Figure 2.28: The flexibility of fire combustion to meet multiple energy needs simultaneously (adopted from Howells & Alfstada, 2005)

Van der Kroon, *et al.* (2013) highlighted the advantage of open fires as providing multiple benefits from one source (Figure 2-27). A single open fire can be used for cooking, heating, and lighting as indicated in Figure 2-28 (van der Kroon, *et al.*, 2013). Electricity is used mainly for light, and firewood used for cooking and thermal purposes. Based on the large number that prefers firewood for cooking because of taste, the interventions required too much cleaner energy should focus on solutions that do not take away any benefits of firewood from the people. This should give the people the freedom to switch from one fuel to the other without limitations such as fuel affordability and accessibility.

Studies have also consistently shown that the use of firewood in households is related to indigenous and sociocultural levels of perception. For cultural, faith and religious reasons, some groups from the selected countries used firewood. For these factors, among others, even though they have access to electricity, most communities do not avoid using firewood.

Culture, tradition, and food taste

Fuel selection for cooking and heating is affected and moderated by cultural practices and beliefs. In the Limpopo province, it is culturally prevalent to cook porridge with firewood, as it is believed to taste better than when cooked with stoves (Makhado, et al., 2009). Ifegbesan, *et al.* (2016) also noted the same results from Nigerian respondents who mentioned that the flavour added to food by utilising firewood was the key to better tasting food. Moreover, the taste and cooking process factor on fuel choice was stated by van der Kroon, *et al.* (2013: pp. 507): "*Although migrants can afford LPG and indeed purchase LPG stoves, they rarely use these stoves because the adoption of this new fuel also requires changes in food preparation traditions. Guatemala's two staple foods, beans, and corn require many hours of cooking and gas is considered too expensive for long cooking processes*".

In North China, more than 60% of the households indicated a preference of wood, and/or straw for cooking purposes as these fuels enhanced food flavour (Wu, et al., 2017). A correlation between age of homeowner and culture/tradition regarding fuel choice for cooking was indicated by other researchers; older homeowners prefer cooking with firewood as part of their culture and for the better taste of traditional food as seen in Figure 2-29 (Mensah & Adu, 2015; Uhunamure, 2017; Semenya & Machete, 2019).

It is worth noting that none of the factors is exclusively independent of the other. Taking the effect of household head’s gender; women who earn an income are most likely to use cleaner fuels than firewood. On the contrary, women with no source of income are most likely to use firewood. A household can be ranked higher on the income bracket, however, due to a bigger household, they may not afford to use electricity to meet all their energy needs. Wu, *et al.* (2017) supports the argument that household demographics are correlated to fuel choice, by noting an association between the age of the homeowner, level of education and reliance on traditional biomass fuels as follows:

i. Approximately 71% of respondents had no understanding of the distinctions between outdoor air pollution and indoor air pollution.
ii. Nearly 78% of individuals know nothing about the factors contributing to indoor air pollution.
iii. Close to 36% of respondents believe that solid fuel combustion has little impact on the quality of indoor air, and do not accept that indoor air pollution can affect their health.
iv. In that sample, the average age of individuals was 58, showing that many elderly people live in rural areas, and they typically have low levels of knowledge and education.
v. The percentage of households choosing solid fuels as the primary cooking fuel is higher when the person is older,
vi. The proportion of those who prefer solid fuels as the main cooking fuel accounts for 61% when people are between 60 and 80 years of age and their average schooling years are five years.

Individuals between 20 and 40 years of age, with an average of eight years of schooling, account for 22% of the solid fuel users.

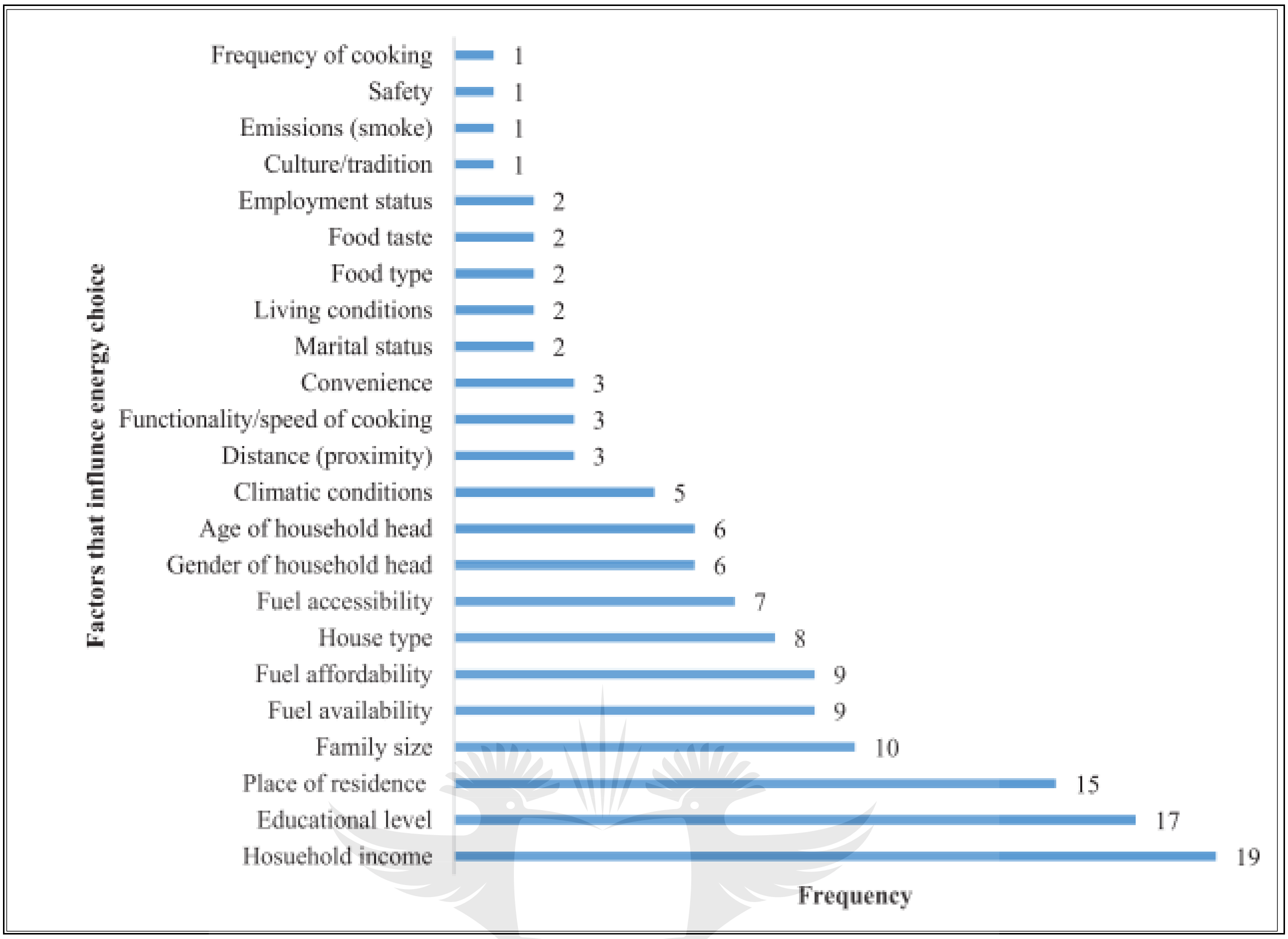

Figure 2.29: Factors influencing fuel choice in Bapedi households of Senwabarwana (Semenya & Machete, 2019)

Traditional biofuels are associated with social costs that are crucial to energy planning; however, these costs are not fully internalised in the market and a non-market section of fuels and appliances (Ouedraogo, 2017). Models should estimate fuel choices and appliances separately from energy services because households use a variety of energy sources for one energy service (e.g., firewood or electricity for cooking) or one energy source for a variety of energy services (such as firewood for cooking, space heating and water heating) (Howells & Alfstada, 2005; Ado & Darazo, 2016).

Energy management strategies that model energy supply and demand are essential for effective utilisation of energy resources, improving energy efficiency and reliability and reducing greenhouse gas emissions (Howells & Alfstada, 2005; Ouedraogo, 2017). Adequate energy planning and management policies are crucial for economic development and environmental security in South Africa (Ouedraogo, 2017). Effective energy solutions to expand access to modern energy services for rural communities are necessary for overcoming African energy services challenges (Israel-Akinbo, et al., 2018). The financial benefits of installing PV and battery depend primarily on the area of installation, market price, incentives, grants, load profile, and irradiance (Baurzhan & Jenkins, 2016).

With this background on the fuel types used and factors affecting fuel choice, the researcher was in a better position to investigate ways that the rural households of Atok can benefit from solar photovoltaic as an alternative source of energy.

2.4. Case studies

2.4.1. Off-grid solar PV for SSA rural electrification

Jamal (2015) researched to evaluate various off-grid options for rural areas in South Africa. The research used Model for Energy Supply Systems and Their General Effect on the Environment (MESSAGE) (Model for Energy Supply Systems and Their General Effect on the Environment) to decide the optimal choice with adequate reliability. The study considered all the nine provinces of the country separately for review to incorporate the spatial gaps in the supply of renewable resources. The Cape area, for instance, has better wind resources, so the position of wind-based generation will be more efficient than other components.

Two investment scenarios were considered for the study: the first possibility is the situation where the cost of investment is comparatively low, while the cost of operational and maintenance (O&M) is high, and the second alternative is a high investment with low O&M costs. For example, a consumer using both solar panels and low-cost batteries to install a photovoltaic device will have to regularly replace components of the device, which will increase the cost of O&M. The findings of the study showed that grid connection was the marginally preferred choice with a cost per connection of R15 450 ($1 022. 5) (Jamal, 2015). The connection cost was reported to be increasingly rising with the years. Ultimately, if this rise in connection costs persists due to the expansion of the electrification programme and the level of consumer usage remains relatively lower, the grid connection in South African rural areas would no longer be an economical option. The following was concluded by the study regarding the best-suited options:

i. A solar PV and wind hybrid system for Cape region.
ii. Solar PV stand-alone or a hybrid system of solar PV with a diesel generator for the other parts of South Africa.
iii. Solar PV with diesel generator hybrid is a more secure and economical alternative on a short-term basis compared to PV standalone, but still, the option attributes maintenance issues.
iv. The options that include diesel generator required more technical expertise than others because of the motive parts and the relatively complex layout of the diesel generator, thus requiring additional efforts to provide highly skilled services in the areas.
v. Due to CO_2 emissions associated with diesel generators, the solar PV stand-alone was a better option.

vi. To maximize the investment, the off-grid electrification project should be implemented in those remote areas where the provision of grid connections is difficult over the next five to ten years.

vii. Implementing off-grid technology would lead to reducing the country's CO_2 emissions.

Jenkins & Baurzhan (2014) conducted a study on whether or not off-grid solar PV is an affordable or appropriate fuel for rural electrification in Sub-Saharan Africa (SSA). The study focused on five determinants namely: affordability, cost-effectiveness, environmental impact, financing, and poverty alleviation.

2.4.2. Cost-Effectiveness

The LCOE of solar PV was determined and compared to that of grid electricity as well as of diesel generator. LCOE for solar PV was $0.83/kWh, which was very higher than the average SSA tariff of $0.08 and $0.16/kWh in 2014. However, due to other costs involved in electricity generation, this comparison was deemed not suitable for the purpose of the study and the cost to diesel generators was opted for instead. The LCOE for the diesel generator was approximately $0.42/kWh, which was lower than that of solar PV.

South African electricity tariff in 2014 was approximately 8.46c/kWh, which was still relatively lower than the solar PV LCOE. With the initial investment sum spent on a 100Wp solar PV system, an option would be to purchase up to 1.2kWp (1 230Wp) diesel generator that would raise electricity output by more than twenty times. Although the operating costs of diesel generators are higher, households could use increased energy generation for other activities such as water pumping, milling, irrigation or any income-generating operation, rather than only lighting, radio or television (Jenkins & Baurzhan, 2014). This makes diesel generators the most widely used off-grid technology in SSA today and significant source energy. Diesel generators do not only produce electricity for household use, unlike solar PV. Solar PV is intermittent and high-cost technology, whereas diesel generators are conventional and of low cost (Jenkins & Baurzhan, 2014). Due to the higher reliability of the source, the electricity produced by these generators can be used in income-generating activities. These could improve the economic well-being of at least some households even more than the solar PV systems would have been able to do.

Operational and maintenance costs are the second or third largest cost drivers for the overall cost of the solar PV system. They involve the costs of foreseeable repairs, maintenance, and the exchange of parts, such as batteries, and costs associated with annual degrading of the solar nodules (Jenkins & Baurzhan, 2014). Consumers are also unaware of the technological unreliability and decreased durability of the key components of the PV device. O&M costs are often underestimated, especially in the case of low-quality systems failure to maintain the system causes the deterioration of components acceptably, resulting in the system's benefits either being decreased or fully removed. Financial schemes typically focus on the initial investment costs and do not take adequate account of O&M costs. Consumers need to be able to pay loans and cope with O&M costs at the same time, which is the key reason why the rural poor, even with the most attractive credit schemes and incentives, can simply not afford solar PV systems (Jenkins & Baurzhan, 2014).

There is a lack of standard systems for after-sales facilities and a lack of participation from the private sector. With their solar PV systems, people are left on their own after buying them. Many of those able to afford a solar PV system opted to turn to the power company if there was a grid link in their vicinity (Jenkins & Baurzhan, 2014). Grid connection was still preferred over solar PV due to its income-generating benefits such as enabling refrigeration storage of fish caught and rice milling (Jenkins & Baurzhan, 2014).

2.4.3. Affordability

The overwhelming majority of the rural poor are unable to bear the upfront expense of solar energy. As they have low and/or erratic incomes, the vast majority of the rural poor cannot afford the upfront expense of a solar PV system, which makes it impossible to save money and pay the whole amount at once. The average five-member household in Africa has a monthly budget of less than $180, which can be as low as $60 (Jenkins & Baurzhan, 2014). Due to its prohibitively high costs, solar PV has been regarded by some energy experts as an unfeasible energy technology for SSA. For most SSA residents, solar PV remains an out-of-reach technology and this is not expected to improve in the short to medium term, despite dropping PV prices and financing developments (Jenkins & Baurzhan, 2014). The monthly cost of solar PV based on LCOE of $0.83/kWh was $51/kWh, which is in the same range as the 2014 annual cost of kerosene lamp of $57/kWh in SSA countries. Affordability of solar PV continues to be a barrier for SSA countries.

2.4.4. Financing issues

Household owners have identified distinction between solar PV and diesel generators. Solar PV installation commits people to a long-term financial obligation involving the repayment of a sizeable debt, whereas with kerosene lighting they are buying energy sources in accordance with their needs and budget constraints. The annualized cost of solar PV is determined by increasing the cost of financing over the entire 20-year life of the plant, which is not in line with reality. In general, micro-finance institutions or commercial banks need both a short payback period, which makes periodic payments much greater and some form of collateral that cannot be provided by many rural customers. Most rural households are without a regular monthly household income, only a limited number of households with teachers; nurses or civil servants have a consistent and adequate monthly income. An intermittent revenue source makes it very difficult to receive and pay for a loan, as is the case with a solar PV system (Jenkins & Baurzhan, 2014).

Traditional energy expenditure is of average value and does not generally reflect daily monthly energy expenditure. For example, in times of economic recession, expenditure on alternative energy sources may be reduced or changed to meet income constraints. However, monthly contributions to financial institutions cannot typically be cut or changed (Jenkins & Baurzhan, 2014). The installation of a solar PV system does not necessarily lead households to avoid buying conventional energy sources. Any households that can afford to continue to use kerosene lamps to save energy from the solar PV system for television watching (Jenkins & Baurzhan, 2014).

Estimation of solar PV should be based on household income constraints, and not on hypothetical energy expenditure, even for households with a regular income. The quantity of PV electricity consumed depends on the marginal utilities per unit of cost derived from both consumer goods. Only if the marginal utility of PV electricity is greater than that of conventional energy applications per unit of the cost would customers be able to pay higher amounts for it (Jenkins & Baurzhan, 2014). In the world, a few operating micro-finance institutions are providing SHS credit for service schemes of the Energy Services Company (ESCO) kind. Additionally, such loans are mainly intended for income-generating activities such as agriculture and crop cultivation. Financial institutions generally demand a productive use of loan applicants' credit that SHSs generally do not satisfy. Due to the inability of solar PV to generate income, the financing cost of solar PV systems remains too high for most rural households, automatically excluding solar PV from lighting options (Jenkins & Baurzhan, 2014).

2.4.5. Environmental considerations

For health and global environmental reasons, solar PV technology is often promoted in SSA. Fine particles, nitric oxides, carbon monoxide, and sulphur dioxide are released when burning kerosene indoors, thus raising the risk of respiratory diseases and lung cancer. Elimination of kerosene and candles could minimise GHG emissions, thus improving the health of the users, and would have a positive impact on the environment as well. GHG emissions from household cooking are relatively higher. Solar PV offers GHG emissions reduction at a cost of $150–626/t$CO_2$, which is higher than the current price of CO_2 emission permits being traded anywhere in the world today and the current estimates of the marginal economic cost of CO_2 emissions (Jenkins & Baurzhan, 2014).

An initial evaluation of Clean Development Mechanism (CDM)-type projects in developing countries was carried out by the United Kingdom (UK) Department for International Development and found that improved cooking stoves (ICS) had a far higher effect than solar PV in terms of reducing GHG emissions, since cooking accounts for a higher proportion of household energy usage (Jenkins & Baurzhan, 2014). The cost of reducing GHG emissions by ICS is between \$40-190/tCO_2. They also found that there is no impact on the environment from solar PV systems. The implementation of ICSs therefore has far better outcomes than solar PV lighting systems, rendering solar lighting systems the least favoured choice for reducing emissions and reducing costs. Decision-makers should take note of this when considering solar PV projects for carbon emission reduction mechanisms in developing countries, such as the CDM defined by the Kyoto Protocol (Jenkins & Baurzhan, 2014).

2.4.6. Household priorities and poverty alleviation

By buying a solar PV system that would add nothing to their living standards, households that can barely afford to buy a PV system may find themselves drawn into long-term debt. The issue here is the problem of priorities: the amount spent on a solar PV system could be spent on anything else that would improve households' economic well-being even more than lighting would, such as improved health, nutrition and education (Jenkins & Baurzhan, 2014).

The expectation that solar PV technology can alleviate poverty has been one of the significant drivers of attempts to disseminate solar PV in SSA. There is, however, no clear proof of rural development benefits resulting from renewable energy. There are undoubtedly social benefits from the illumination, TV, radio, and charging of telecommunications equipment by solar PV systems, and some economic benefits from the reduced usage of candles and kerosene (Jenkins & Baurzhan, 2014).

In Zambia, the ESCO project has improved household welfare, but mainly the electric light aspect by the improvement of the quality of light, especially in terms of opportunities to study more at night. Effective economic growth, however, has not been pursued by rural electrification projects, given that the requisite economic infrastructure and skills are not funded. Economic benefits from rural RE programs are more likely to occur in n areas where economic growth already exist (Jenkins & Baurzhan, 2014). Only those who are able to afford solar PV systems and the necessary infrastructure to convert energy into useful services and productive activities can benefit the most from having solar PV (Jenkins & Baurzhan, 2014). Based on experience with the dissemination of small-scale PV systems in developing countries, it has been noted that little evidence exists that these systems have an impact on the alleviation of poverty. Household purchase SHSs for improved services such as longer TV watching and better lighting efficiency, not because these SHSs lower their energy costs (Jenkins & Baurzhan, 2014).

A multi-attribute decision analysis was performed for various CDM projects in developing countries, where SHSs scored 0 out of 100 for poverty alleviation, while ICSs scored 90. This demonstrates that high-technology emphasis does not necessarily lead to direct alleviation of poverty. The acquisition of a solar PV system at the household level is a lower priority for rural households than for other basic needs and commodities. Only after these other needs have been met can solar PV systems become an option. Lighting isn't always a priority for the poorest of the rural population (Jenkins & Baurzhan, 2014).

Table 2.7: Cost savings offered by alternative renewable energy sources.

Author	Study area	Year	Current fuels	Alternative Fuels	Cost Savings ($/kWh)
Shah & Al-Awami	Saudi-Arabia	2018	Grid electricity	PV and battery	2.48
Mandal *et al.*	Bangladesh	2018	Grid electricity	PV/Battery/Diesel	0.271
Tam *et al.*	Australia	2017	Grid electricity	PV	0.31
Garrido *et al.*	Mozambique	2016	PV/Diesel	PV/Battery/Biomass	0.1
Rahman *et al.*	Developing countries	2014	Traditional and fossil fuels	PV and biogas	1.12
Sen & Bhattacharyya	India	2014	Traditional and fossil fuels	Hydro/PV/Battery/Biodiesel	0.5

The results of studies conducted in various parts of the world to compare currently used fuels and alternative fuels such as solar PV, wind, diesel, battery and/or hybrid systems are presented in Table 2-7. A study on financial benefits of installing a solar photovoltaic system and lithium-ion batteries in Saudi-Arabia households revealed the average daily electricity cost is the lowest when using a combination of PV and batteries (Shah & Al-Awami, 2018). The electricity costs were compared to those of grid electricity (no PV and no batteries), PV only and batteries only. Batteries only came second, followed by PV only and lastly the grid electricity as the costliest option (Shah & Al-Awami, 2018). According to Palm (2018), more households in Sweden started investing in PV systems from 2014 due to the available subsidies, profit made from selling micro-generated electricity to the grid, environmental and other economic benefits. Cost savings of between $309/year to $412/year were recorded by Rahman *et al.* (2014), for households displacing traditional biomass and fossil fuels with solar PV and biogas hybrid system.

The economic benefits of PV and battery system against diesel and battery system or grid electricity were revealed by a study done in Bangladesh (Mandal *et al*, 2018). Rahman *et al.* (2014), and Sen &

Bhattacharyya (2014), provided some of the potential greenhouse gases emission reductions associated with displacing fossil fuels and traditional biomass with solar PV; with carbon dioxide emissions reduction up to 38kg/yr and carbon monoxide reduction of up to 44kg/yr. A study on the life cycle cost-effectiveness of using photovoltaic solar systems in households over a 25-year period was done in eight major Australian cities and revealed that residents can receive life cycle cost saving of between \$2 806 and \$119 542 (Tam, et al., 2017). The financial benefits of installing PV and battery depend largely on the area of installation, market price, incentives, grants, load profile, and irradiance (Sen & Bhattacharyya, 2014; Palm, 2018; Shah & Al-Awami, 2018).

The SHS in Bhutan, Southern Asia was initiated as a way of electrifying the rural households in the mountainous terrain where grid electricity connection deemed impossible, economically unviable and technically infeasible (Dorji, 2012). Due to the demography of remote areas, the socio-cultural status of the population, extensive distance from the grid, and economy of the rural households, there is energy services demand that need to be met with off-grid electrification. The SHS program in Bhutan encountered problems such as lack of maintenance, misuse of the system leading to premature failure of the components, inappropriately sized systems due to lack of radiation data, and not educating users on the operation of the systems (Dorji, 2012).

2.4.7. Financial benefits of PV and energy storage for households in Saudi Arabia

In Shah & Al-Awami (2018), the cost of meeting household load based on a 6kW PV system was determined for different scenarios (Figure 2-29). The study took into consideration the lifetime of the PV system, its cost, battery size, its output power, its charging and discharging rate, cycling, and efficiency. The results presented in the figure show the average annual cost associated with the household load. The PV with battery for storage came out the most economically feasible with a cost of \$2.48/kWh, which is way less than the costliest option of neither a PV nor battery. Installing a PV without any storage deemed costly than having a battery without the PV system (Shah & Al-Awami, 2018). Having both solar PV and battery in this case would save the households about \$2/kWh. PV and batteries are economically viable for households under incentive programmes. The financial benefits of PV and battery installation rely largely on location, market price variation, load profile and irradiance. PV is an appealing option for summer peaking systems where peak generation of PV occurs at peak demand and can therefore match the demand curve, but when the PV reaches a certain limit it could increase the ramping demand for PV units (Shah & Al-Awami, 2018).

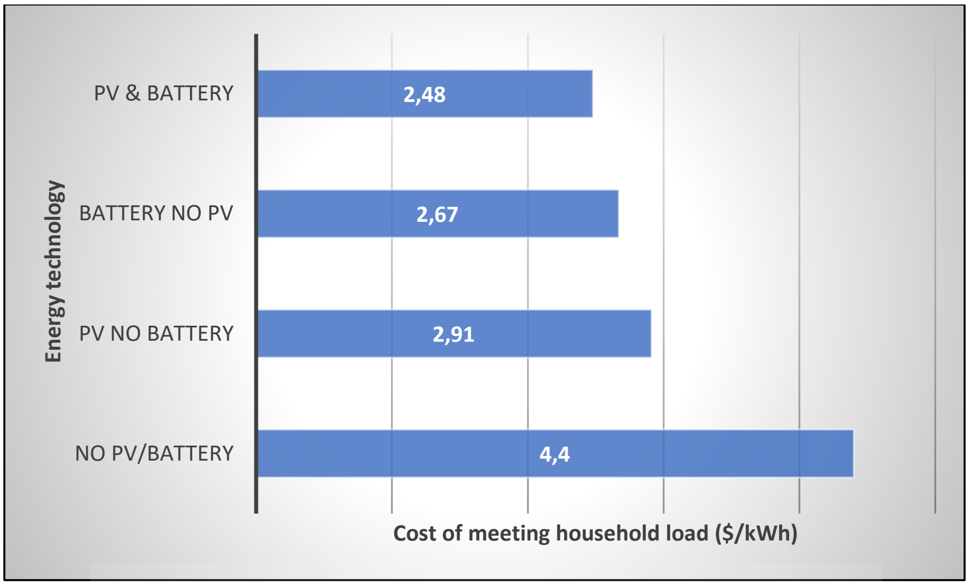

Figure 2.30: Average cost of meeting the household load in Saudi Arabia (Shah & Al-Awami, 2018)

The cost of solar PV systems has dropped and continues to decrease. Expectations of continued cost reductions prevail. Jenkins and Baurzhan (2014) calculated that it would take 16.8 years for solar PV systems to become competitive with diesel generators. When a project's investment cost decreases over calendar time it is often better to postpone such an investment. Thus, it is not advisable for rural communities in the SSA to invest in this technology until around 2030, given the current costs and declining prices of solar PV systems (Jenkins & Baurzhan, 2014).

Tam, *et al.* (2017) analysed the cost-effective life cycle of the usage of PV solar systems ranging from 1.5kW to 5kW in relation to the number of inhabitants and the consumption of residential dwellings over a 25-year period. Australian cities like Sydney, Canberra, Melbourne, Brisbane, Hobart, Adelaide, Darwin and Perth have been investigated and it has been found that all major cities will benefit from life-cycle savings by installing photovoltaic solar systems in their homes. Many of these residential owners in each city paid the initial expense and thus benefited from the savings over the 15-year life cycle. Life cycle cost savings was between $2 806 and $119 542 and the cost savings rate is between 1.85% and 118% over 25 years. It was also found that higher PV system capacity increased the cost savings your life cycle (Tam, et al., 2017). In a study by (Chauhan & Saini, 2015), where renewable energy technologies were analysed and modelled, solar PV was found to be one of the most optimal options for off-grid electrification of rural India.

The study of solar PV electrification and rural energy-poverty in Ghana for households with and without solar PV indicated a positive correlation between the two. The energy-poverty groupings revealed unequal proportions of households in each group (Obeng, et al., 2008). On average, households without solar PV have been comparatively weaker than households with solar PV in terms of access to electricity services. Many non-electrified households fall into the 'energy-poor' category. Such households are likely to use kerosene lanterns for lighting purposes and do not have access to television and radio. The results of this study provide a framework for understanding the relationship between rural solar PV electrification and improved energy poverty status in off-grid communities (Obeng, et al., 2008).

Solar PV has deemed itself as one of the most feasible RE technologies to be considered in rural areas. Either be it a stand-alone technology or in a hybrid system (Isa et al., 2016). Solar PV offers great benefits that should be taken into consideration when planning future rural electrification (Ahmad & Imran, 2018; Alam, et al., 2018).

2.4.8. Challenges faced with implementing RE technologies

A study by Mandal *et al.* (2018), examined the possible implementation in the northern region of Bangladesh of a hybridized energy system (i.e., PV / Wind / Diesel) with battery storage and noted some of the challenges faced with the system implementation discussed here (Figure 2-30). Due to the system topology, the design and implementation of a hybridized power system is a dynamic one and a relatively challenging assignment. In addition, relative to the diesel-only system, the hybridized system requires higher capital investment costs. The business infrastructure to help the components of the hybrid system is inadequate (Mandal et al., 2018). Moreover, the timely replacement of many batteries and the availability of spare parts are also a concern in these remote areas. One of the major problems in developing countries such as Bangladesh to make every project viable is the policy and regulatory issues. Bangladesh's renewable energy policy includes some financial benefits, such as a 15% VAT exemption from the purchase of equipment and raw materials and a 10% higher private-sector purchase price (Mandal et al., 2018).

Barriers and issues	Summary
Technological barrier	• Energy access is quite difficult in remote hills of state • Lack of information regarding resource availability in various parts of the state • Low level of technological maturity • High risk with renewable energy resources like solar, wind etc. as these resources are highly intermittent in nature • Difficult to satisfy peak demand with intermittent renewable energy sources • Need of energy storage/backup technologies for intermittent renewable energy sources like solar, wind etc. that further raise the system cost
Economic barrier	• High initial capital cost of renewable energy products • Lack of financial support from government in terms of subsidies • High transaction cost of fuel for biomass/biogas based power plants • Heavily subsidized agricultural sector • Low investment in research and development (R& D) of renewable energy products
Legal and regulatory	• Inadequate legal institutional frameworks for renewable energy based on off-grid rural electrification • Arduous requirements for the small power producer set by the utility • Lack of technical standard for renewable energy products in market leads to low level of reliability • Lack of clear guidelines for project development from state and central government • Inadequate allocation of funds from state electricity regulatory commission (SERC) for planning off-grid power projects • Need to qualify necessary clearances, like land acquisition, environmental clearance, in order to implement small renewable energy projects • Lack of communication among project owners, project developer, equipment supplier and service provider. • Lack of cultivable land for biomass production.
Human resource	• Not requisite skilled manpower/experts for rural electrification • Experts/technicians willing to work at greater pay • Lack of manpower for operation and maintenance of renewable based projects in rural areas, i.e. collection of pine needles from forest, collection of agro residue from field • Skilled manpower hesitates to go in rural areas compared to urban areas

Figure 2.31: Barriers and Issues faced with implementation of RE technologies in the Uttarakhant state of India (Mandal et al., 2018)

The right policy and regulatory requirements for the technology system's implementation make good energy resources successful (Mandal et al., 2018). Implementation of the hybrid system can be achieved by rebuilding the new laws, not by moving beyond the existing rules and regulations. The government's political commitment is critical to rural electrification with renewables. However, the new institutional framework includes approval from various ministries, agencies and organizations. Therefore, without good coordination with them, it is difficult to get approval for implementation. Introduction of a new RE system as rural electrification requires financial assistance and thus economic considerations is an essential part of the planning of such a programme. Extra funding would be required for new skills training (Mandal et al., 2018). The adoption of a new technology that involves complexity also depends on socio-cultural freedom, as the degree of comprehension of such technology is required. To introduce the standalone hybridized system, the state and private entities should come together with the residents to address these obstacles (Mandal et al., 2018).

2.5. Relevant South African energy policies

The energy industry is governed by policies under the Department of Mineral Resources and Energy (DMRE), previously referred to as Department of Energy (DOE) or Department of Minerals and Energy (DME). The DMRE and its responsibilities were defined by the government as "*The department is accountable to the minister and is responsible for general governance of the energy sector, the formulation of long-term integrated energy policies, communication with stakeholders, the management of investigation and demonstration programs, the management of regional and international cooperation, and ensuring that appropriate institutions are established to achieve energy policy objectives*". Energy policies have the following objectives (DME, 1998):

i. Increasing access to affordable energy services.
ii. Improving energy governance.
iii. Stimulating economic development.
iv. Managing energy-related health and environmental impacts.
v. Securing supply through energy carrier's diversity.

2.5.1. White Paper on Energy policy, 1998

The government drafted the White Paper on Reconstruction and Development policy framework in 1994 (DME, 1998). A part of the policy was the Reconstruction and Development Programme (RDP) framework which included the National Electrification Programme (NEP). The NEP focus was to accelerate the electrification of disadvantaged communities (DME, 1998). The white paper on energy policy was concluded and published in July 1998, replacing the previous policy published in 1986. The purpose of the White Paper was to address an adequate balance between supply and demand, clearly stating government policy regarding the supply and consumption of energy for 10 years starting from 1998. The white paper was formulated to fill the previously neglected energy demand gap of rural communities. The policy acknowledges the integral parts of an energy policy as both technical and social. Key cross-cutting issues in the policy are integrated energy planning; governance and institutional capacities; fiscal and pricing issues; statistics and information; international energy trade and cooperation; capacity building, education and information dissemination; human resources; research and development; environment, health and safety; and energy efficiency (DME, 1998).

2.5.1.1. Demand sub-sectors

The demand side of the policy is for households, industry, mining, commerce, agriculture and transport. The need for clean, accessible and adequate energy for previously disadvantaged households; energy efficiency and conservation; and energy security were at the forefront of the energy policy for households. The policy provides guidelines for the Government such as considering multiple fuels use in one household; the effect of financing the fuels; and affordability, availability and efficiency of the fuels and appliances. On achieving the objective of increasing access to energy services, the government prioritised the following (DME, 1998):

i. Boost the distribution of energy services in households, including electrification.
ii. Establish a national framework of electrification strategy, planning and funding.
iii. Treat electrification off-grid in the same way as grid electrification.
iv. Promote forest development and management for rural households relying on firewood.
v. Establish voluntary guidelines for low-income households' thermal efficiency.
vi. Drive the production of new and renewable energy sources.
vii. Foster improved combustion techniques and firewood appliances and other conventional fuels.
viii. Supporting the creation and implementation of programmes for capacity building, education, and dissemination of information.

In 1997, 60% of the South African households were electrified, however, only 20% of the household energy needs were met with electricity. Firewood contributed 65% to the household consumption, coal 9%, paraffin 8% and little contribution by LPG. Households consumed 24% of the national energy in 1997. The provision of community's infrastructural services such as rural water supply, public lighting, health care, community facilities, education, and transport, requires energy. Energy services are thus crucial to enhancing the quality of life through access to services such as entertainment, lighting, home-based enterprises, and small-scale farming (DME, 1998).

Low-income households were previously neglected in terms of energy needs and electrification. The creation of a new industrialized urban community to meet the needs of the industrial sector and a privileged white minority was a priority of the previous government. The inequality in wealth because of past social and economic policies resulted in a service backlog, no electricity or inadequate electricity for the less privileged. Majority of the electrified households could only afford to use electricity for lighting and entertainment at that time. Such households had to rely on traditional fuels such as coal, firewood, paraffin, batteries, candles, and LPG (DME, 1998). Unemployment and insecurity are a significant factor related to the continued use of non-electric fuels. Low- or volatile-income households prefer to buy fuel as and when cash resources are accessible. Such unstable patterns of energy usage, marked by the use of many fuels for various end-uses, clearly work against energy-efficient and reasonable use. In addition, low-income households prefer to buy inexpensive and dangerous appliances, thereby rising health risks.

The limited use of electricity is due to constraints such as the high cost of electrical appliances, their lack of multi-functionality and the comparatively high cost of thermal end uses such as cooking and space heating. Unlike higher-income households which almost entirely depend upon electricity to meet all their energy needs, multiple fuel use and emphasis on traditional and low-cost fuels is likely to prevail in rural low-income households. The use of firewood and coal has negative health impacts on users, such as respiratory illness. Department of Water Affairs and Forestry, in co-operation with the Department of Minerals and Energy, the Department of Agriculture, the private sector, provinces, and local communities were placed in charge of the programme to facilitate the development and maintenance of woodland for the benefit of rural households through a national social forestry programme (DME, 1998). Great consideration of involving women, as the primary energy users in households, in public policy formulation is critical to an effective energy policy (DME, 1998).

The energy supply sub-sectors are electricity, nuclear energy, oil and gas, liquid fuels, renewable energy, coal, and transitional fuels (low-smoke fuels). Eskom is the national electricity baseload supplier. Eskom generates, transmits, and distribute more than 80% of the national electricity. The policy was addressing the following challenges faced by the electricity industry (DME, 1998):

i. Around 40% of all households in South Africa and tens of thousands of schools and clinics do not have access to electricity.
ii. With more than 400 distributors, the distribution sector of the industry is highly fragmented, resulting in low efficiencies, high prices, large tariff disparities and financial viability problems for several distributors.
iii. There are still high levels of non-payment and energy theft in the electricity distribution sector, resulting in rising arrears and payment defaults.
iv. The electrification programs of most municipal distributors are constrained by the difficulties of accessing affordable finance, aside from a few notable exceptions.
v. There was anticipation that municipal electricity departments will contribute to the financing of other municipal services, especially in major urban areas, but they will also face the burden of non-payment and the need for substantial electrification expenditure.
vi. Coal-based production of electricity results in large polluting emissions with possible long-term environmental impacts.
vii. Electricity is inefficiently used in some cases, possibly because of a market belief that electricity is free, thus wasting precious energy and capital resources.
viii. Although inflationary pressure on prices may result from several challenges described above, South Africa must retain the competitive advantage of low, stable, and cost-reflective electricity prices.

The government must achieve an acceptable balance between reaching equity, economic growth, and environmental objectives in its approach to electricity pricing policy. The pricing policy must provide a guideline for competitive household electricity prices, low-cost industrial electricity prices, prices that provide effective market signals by accurately representing the cost of production, and a general price level that ensures the financial sustainability of electricity utilities (DME, 1998).

2.5.1.2. Integrated resource planning (IRP)

Integrated resource planning (IRP) is a decision-making mechanism for obtaining low-cost energy resources that consider the need for all consumers to establish sufficient, efficient, safe, and environmentally friendly energy services. The mandatory use of IRP methodologies would ensure that utilities prevent or defer improvements in the supply of electricity or defer decisions to decommission when it is cost-effective to do so by maximizing the use of existing resources and the quality of energy supply and usage. The following approach was followed for the IRP in 1998 (DME, 1998):

i. Evaluation of all candidate services for energy supply and demand in an impartial way.
ii. A wide range of economic, environmental, social, and technical influences are routinely considered.
iii. Considering the risks and uncertainties that various resource portfolios and external factors pose, such as fuel price fluctuations and economic conditions.
iv. Facilitating public consultation in the phase of utility planning.

The non-utility generation policy was created as part of the IRP to promote entry of multiple electricity generators into the energy market, enabling economic exploitation of the full potential for non-utility generation in South Africa. This policy also encourages the development of renewable energy technologies such as solar, wind, hydro, and waste incarceration (DME, 1998).

2.5.1.3. Renewable energy sources

The development of the government's renewable energy policy is driven by the rationale that South Africa has incredibly attractive renewable resources at its disposal, especially solar and wind and that renewable applications are, in many cases, the least cost-effective energy service, in addition to considering environmental and social costs. The policy is based on the understanding that renewable energy sources are independent, they are not confined to small and remote applications, and that they have considerable market potential in the medium and long term. The renewable energy policy was formulated to address the following challenges (DME, 1998):

i. Constraints faced with the renewable industry's growth.
ii. Ensuring the implementation of economically feasible technologies.

iii. Ensuring that national resources are invested in clean energy on an equal basis.
iv. Closed mind-sets, as an obstacle to the implementation of technologies for renewable energy.

The prioritised RE sources were solar PV, solar water heating systems, passive building design, biomass, micro-hydro, and wind-based electricity systems. In supporting renewables, the policy stated: "*Government will provide focused support for the development, demonstration and implementation of renewable energy sources for both small and large-scale applications*" and "*Government will support renewable energy technologies for application in specific markets on the basis of researched priorities*." About 1 400 rural schools and 300 rural health clinics had already been electrified with solar PV systems in 1998. The targeted receivers of solar cookers, SHS, solar water heaters and solar water pumps were several rural schools, households, and clinics (DME, 1998).

2.5.1.4. Integrated energy planning (IEP)

The integrated energy planning (IEP) is a process that follows this approach (DME, 1998):

i. Interpretation of the national social, environmental, and economic policy criteria for the energy sector.
ii. Analysis of energy needs and how their fulfilment will contribute towards attaining national social and economic aims.
iii. Analysis of the potential of energy supply systems and demand-side management to meet current and potential future energy demand.
iv. Analysis of individual supply sub-sectors and the linkages between sub-sectors.
v. Analysis of the link between the energy sector and the macro-economy.
vi. Analysis of the potential effects of global and technological developments on the energy sector.
vii. Evaluation of the effects of institutional, legislative and industry structure arrangements on energy supply and demand.
viii. Specification, procurement and presentation of data on energy supply and demand, institutions of the energy sector and ties to economic and social factors in order to provide a statistical overview of the historical evolution of the energy sector and its current effects on economic and social growth.

The IEP has multiple objectives, some of which include:

i. Guiding the development of energy policies and setting the framework for regulations in the energy sector.
ii. Provide guideline in the selection of appropriate technologies to meet energy demand.

iii. Direct investment and the development of energy infrastructure in South Africa.
iv. Propose new strategies on alternative energy.

The execution of the IEP faced challenges such as follows (DME, 1998):

i. Linking electricity into the infrastructure investment plan for municipalities.
ii. Maintaining a balance between supply and demand.
iii. Facilitating the development of a least-cost energy system.
iv. Establishing and maintaining adequate structures and systems to carry out IEP purpose.
v. Incorporating IEP technical functions into policy-formulation.

The first IEP (1) was formulated as recommended in the White paper and published in the year 2003, stating the following (DME, 2002):

i. Maintain reliant on coal for energy supply (including new generation) for at least the next two decades.
ii. Explore nuclear options further.
iii. Diversify energy supply.
iv. Encourage energy efficiency.
v. Minimise levelized lifecycle costs of the electricity generation plants by maximising their load factors.
vi. Explore oil and gas deposits.
vii. Increase existing oil refineries.
viii. Keep current sinful plants and supplement feedstock with natural gas.
ix. Promote environmental considerations in energy supply, transformation and consumption.
x. Promote access to clean and affordable energy.
xi. Introduce regulation, legislation and policy for promoting renewable energy technologies and energy efficiency.
xii. Conduct integrated energy planning on an on-going basis.

The IEP presented scenarios that could be applied to both the supply and demand sides of energy over 2 decades, starting in 2003 (Table 2.8). The scenarios presented were as follows: 1. business as usual, 2. Diversification and 3. Low carbon cases. The scenarios for households' demand, coal and renewable energy supply are detailed in Table 2-8 (DME, 2002). Business-as-usual is based on current situations, without policy intervention, being the least-cost approach, and assumes an increase in demand. The diversification scenario is a modification of the baseline/business as usual, looking at an optimal diversified solution through a blend of various energy sources, i.e., what will be the least cost energy mix after policy intervention). The low carbon scenario focuses on interventions required to reduce greenhouse gases, energy efficiency, fuel switching, development of renewable energy, clean coal technology, hybrid cars, nuclear energy, alternative mode of transport such as electrified cars/trains (DME, 2002).

Table 2.8: IEP energy modelling scenarios for 2003 to 2022 (DME, 2002)

Scenario	Business as usual	Diversification	Low carbon
Households demand drivers	Security of supply Grid and off-grid electrification planning Biomass, coal and paraffin remain dominant for low-income households	Health and safety Continue with electrification. LPG and ethanol gel to replace paraffin. Solar water heaters Basa njengo magogo programme Biomass	Availability of finance/ subsidies Affordability Appliance labelling is mandatory. Switch to solar technology due to its competitiveness. Gas stoves Health, environment, and safety considerations Thermal building standards to mitigate climate change.
Coal drivers	Security of supply Coal remains dominant	Health and safety Efficient ways of burning coal	Ecologically driven/international commitment External and internal pressure Social and environmental impacts Health and safety Availability of finance/subsidies Emission trading Cleaner development mechanism Competent renewable energy market
Renewable energy	RE technologies are costly compared to coal Security of supply	Slowly forcing RE technologies into the energy mix Availability and affordability	Reliability Incentives for using RE technologies. Improved technology and cost-saving Finance availability Ecologically driven. Emission trading International commitment

2.5.1.5. Energy Efficiency (EE)

Energy efficiency is using less energy to provide goods and services, without compromising on desired benefits, and thus minimising energy waste (DME, 2003). Energy efficiency should be included in an energy policy framework and with the IRP. The EE policy for households stated that "*Government will promote energy efficiency awareness in households and will facilitate the establishment of relevant standards and codes of practice for the thermal performance of dwellings, the inclusion thereof in the national building codes, and will promote their implementation through appropriate measures*". An educational programme on dealing with the costs and benefits of building dwellings with good thermal performance was suggested for funders, designers, builders and homeowners. The Government would facilitate the implementation of a programme for domestic appliance labelling and make the homeowners aware of the labelling through public campaigns.

2.5.1.6. Environment, health and safety

The energy sector has both negative and positive impacts on the environment, health, and safety. The roles of the Department of Environmental Affairs and Tourism's National Environmental Management Bill as the responsible department for the effects of energy on the environment are detailed as follows:

i. Prioritising people's energy needs and serving their interests equitably.
ii. Ensuring socially, economically, and environmentally sustainable energy developments.
iii. Promoting public participation in policy-formulation regarding the environment.

The Government's commitment to the health and safety of the citizens is to mitigate the negative health and environmental impact of coal and firewood use in households, by promoting and developing the following strategies:

i. Replacing bituminous coal with clean fuels such as low-smoke fuels and LPG.
ii. Improving the thermal setup of households to reduce space heating required in winter.
iii. Intensifying electrification of households.
iv. Improving ventilation in old and new houses e.g., installing chimneys.
v. Improving stoves, coal and wood-burning practices in terms of performance and safety.
vi. Developing awareness programmes on the above-mentioned strategies.
vii. Developing and introducing safer paraffin stoves.
viii. Monitoring and assessing the safety measures provided by the petroleum industry.

South Africa ratified the 1997 Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC). UNFCCC is a global community formed to address issues of climate change. The South African National Committee for Climate Change encouraged the ratification of the Kyoto Protocol because the energy sector is one of the key contributors to climate change. Potentially, South Africa as a major coal consumer and exporter would be affected by national and international carbon emissions commitments. The government made these commitments in the White Paper (1998):

> "*Government will monitor international developments and will participate in negotiations around response strategies to global climate change, in order to progressively balance its environmental responsibilities and development interests, along with health-related local issues, in these processes. The Department of Minerals and Energy will follow a 'no regrets' approach in the energy sector with regard to the potential global environmental impacts of energy activities*".

2.5.2. Free basic electricity, 2003

In 2000, the South African government announced its intention to provide Free Basic Services to all the poor communities. During the year 2003, Free Basic Electricity (FBE) policy was gazetted by the South African government (Adam, 2010). In the context of FBE, a household is a residential customer that has an official point of electricity supply (DOE, 2018). According to the Department of Minerals and Energy:

> "*FBE is the amount of electricity, which is deemed sufficient to provide basic electricity services to a poor household. This amount of energy will be sufficient to provide basic lighting, basic media access, basic water heating using a kettle and basic ironing in terms of grid electricity and basic lighting and basic media access for non-grid systems*" (DME, 2003).

The FBE program is aimed at providing low-income households with free electricity of 50kWh per month, which is believed to be adequate (Adam, 2010). However, the monthly electricity consumption of appliances used in an average low-income household is way higher than the proposed FBE of 50kWh as seen in Figure 2-32 (136.7kWh per month required). Ruiters (2009) stated that a small refrigerator switched on for 24 hours a day; 30 days a month would consume approximately 200kWh (Figure 2.32). Researchers have highlighted that FBE of 50kWh is inadequate (FBE, 2003; DOE, 2009; Ruiters, 2009; DOE, 2016). Only 27% of South African rural households and 31% of Limpopo low-income households receive FBE (DOE, 2016).

Ngeva (2019) revealed that the FBE implementation faced challenges such as lack of technical resources, lack of education and awareness, shortage of human capital, funding challenges, and infrastructural challenges. Not all households that qualified for the subsidy due are benefitting from it due to various issues such as inconsistency in the registration process, unregistered meters, irregular updates of indigent registers, and tampered meters (Ngeva, 2019). The issues mentioned above relating to FBE explain the much lower than expected rate of households transitioning to electricity usage, albeit the FBE program implementation. Limpopo is still one of the provinces experiencing high energy poverty in the country, despite the electrification programmes interventions.

Item	Watts	Hours used	Days used	kWh
1X energy-saver light	11	5.0	30	1.7
1X TV (B&W)	35	6.0	30	7.0
1X iron	1000	4.0	6	24.0
1X kettle	1000	0.5	30	15.0
1X hotplate	1000	1.0	25	25.0
1X regular light	100	5.0	30	15.0
1X refrigerator (small)	250	6.5	30	49.0

Figure 2.32: Monthly electricity consumption per appliance in low-income households (DOE, 2016)

2.5.3. White Paper on renewable energy (2003)

The white paper on RE was formulated to accelerate South African government's overall vision which states, "*An energy economy in which modern renewable energy increases its share of energy consumed and provides affordable access to energy throughout South Africa, thus contributing to sustainable development and environmental conservation*". Renewable energy technologies produce electricity, gaseous and liquid fuels, heat, or a combination of these energy types from naturally occurring non-depletable sources. Examples of RE technologies include wind, solar, hydro, biomass, tidal, wave, ocean current and geothermal (DME, 2003). The need for a policy that promotes renewable energy introduction into the energy mix arises from high reliance on coal power plants and firewood (in rural areas). The issue of environmental considerations, energy security and diminishing resources can be addressed by diversifying energy sources i.e., introducing RE sources to the energy mix. The government's task is to establish a policy environment with sufficient legal, fiscal and regulatory resources that attract domestic and foreign investment, while at the same time ensuring that national policy priorities are achieved, and that the energy mix is adequate. The following challenges faced with implementation of RE sources were identified (DME, 2003):

i. Lack of awareness on opportunities and benefits of RE sources.
ii. Legal, financial, organisational and regulatory barriers.
iii. Restricted access to key energy infrastructure such as the electricity grid.
iv. The social and economic system of energy services is based on centralised development around conventional sources of energy.
v. High initial capital cost and long period investment before profitability.
vi. Utility market power.

South African daily solar radiation ranges between 16 and 23MJ/m^2, which is amongst the highest solar radiation globally (Council for Scientific and Industrial Research (CSIR), 2001). Solar PV and thermal electricity generation are not fully explored due to back-up and energy storage. Solar has various uses and applications as listed below (DME, 2003):

i. The technique of solar passive building design for residential, commercial and industrial buildings to reduce the use of thermal energy.
ii. Solar water heating, space heating and cookers (including heat pumps).
iii. Agricultural use such as crop drying, greenhouse etc.
iv. Solar PV and thermal for electricity generation.

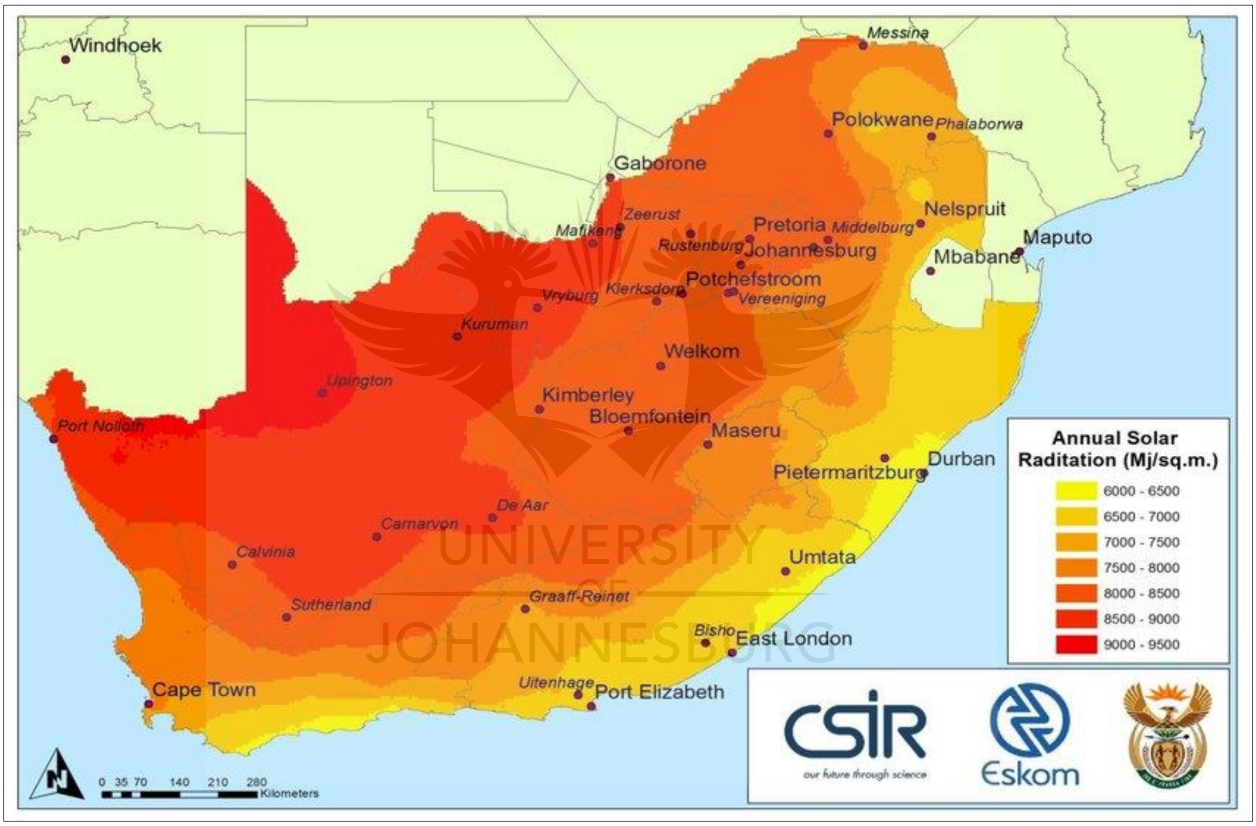

Figure 2.33: South African Annual Solar Radiation (CSIR, 2001; DME, 2001; Eskom, 2001)

The RE white paper concluded that to recognize innovations that may be especially suitable for the South African situation in the long term, the government will track global technological advances in renewable energy, making the best use of collaborations, both locally and globally, where possible (DME, 2003).

2.5.4. Integrated National Electrification Program (INEP), 2004

In 2000, the responsibility for electrification was shifted from Eskom to the Integrated National Electrification Program (INEP) under the Department of Minerals and Resources (DME). The emphasis turned to the electrification of rural areas. INEP aims to provide access to electricity for all households by 2025, either by grid or non-grid (usually solar) connections. By 2016, access to electricity had improved to 84% of the households.

2.5.5. National Energy Act, 2008

The 2008 National Energy Act (Act 34 of 2008) was established to ensure that various energy resources in South Africa are available in sustainable quantities and at reasonable prices. Furthermore, the Act provides for expanded use of renewable energy sources, an emergency supply of energy, the holding of strategic energy feedstock's and carriers, and sufficient investment in energy infrastructure.

2.5.6. Nuclear Energy Policy, 2008

The nuclear industry in South Africa is primarily regulated by the Nuclear Energy Act 1999, Act 46 of 1999 and National Radioactive Waste Disposal Institute 4 Act, Act 53 of 2008. In October 2008, the Cabinet approved the Nuclear Energy Strategy for South Africa which outlines the vision of the South African Government for the implementation of a comprehensive nuclear energy program by ensuring that the Government's goal for the prospecting and mining of uranium ore and the use of uranium (or other related nuclear materials) as a primary energy resource must be controlled and handled in a manner that is for peaceful purposes. The government stated the following objectives to be achieved through the Nuclear energy policy (DMRE, 2008):

i. Development of new nuclear-related skills
ii. Promoting nuclear energy as an important electricity supply fuel by establishing a national industrial capability for the nuclear energy systems' design, manufacture and construction.
iii. Establishing a system for the safe and stable use of nuclear energy with minimal environmental impact.
iv. Guidance on the growth, promotion, support, change, maintenance and monitoring of the nuclear energy sector in South Africa.
v. Creation of a necessary framework for an extended nuclear energy programme.
vi. Exercise control over unprocessed uranium ore for the benefit of the South African economy for export purposes.
vii. Contribution to the country's growth and development in social and economic transformation.

viii. Establishing mechanisms to ensure the availability of land for future nuclear power generation (nuclear sites).
ix. Improving the quality of human life and encouraging the development of science and technology.
x. Curbing greenhouse gas emissions.
xi. Achieving global leadership and self-sufficiency in the long-term nuclear energy market
xii. Promoting energy security for South Africa.
xiii. Enabling the participation of public entities in the value chain of uranium (DMRE, 2008).

2.5.7. Integrated Resource Plan (IRP), 2010 & 2019

The IRP is a proposal to produce energy infrastructure focused on the lowest cost of electricity supply and demand balance, considering supply protection and environmental sustainability by focusing on reduced emissions of greenhouse gases, affordable electricity, diversified sources of electricity production, reduced consumption of water, localisation and regional growth (DMRE, 2019). The enacted IRP 2010-2030 defined the preferred generation technology needed to meet the anticipated growth in demand up to 2030. Key assumptions including the electricity demand projection, performance of Eskom's existing plants, and new technology costs changed since the promulgation of IRP (2010-2030), and this birthed IRP 2018 draft (DMRE, 2019).

The energy sector alone accounts for approximately 80% of total pollution, of which 50% comes from the generation of electricity and the production of liquid fuel alone. The timing of the transition to a low-carbon economy must be socially just and attentive to the possible impacts on jobs and local economies. To continue using our coal resources in an environmentally friendly future, considerations of carbon capture and storage, underground coal gasification, and other clean coal technology are crucial. There will need to be a balance between energy security, the adverse health effects of poor air quality, and the economic costs associated with the closure of Eskom plants that are non-compliant to the air quality standards. At all stages of the electricity supply chain, Eskom has played a critical role as the dominant vertically integrated utility. The role is anticipated to change with the 2019 decision to unbundle Eskom by separating the generation, transmission and distribution functions (DMRE, 2019).

The actual annual net sent out electricity in 2018 (245TWh) differs by 90TWh from the projected 335TWh (DMRE, 2019), such a huge difference suggests that long-term commitments should be limited, and that the IRP should be updated regularly in line with the ever-changing technology upgrades, demand and economic growth. Improved energy efficiency, fuel switching from electricity to LPG for cooking and space heating, increased embedded generation, and electricity supply cut-offs have plumbed the overall electricity usage. An increase of between 50% and 60% of the current electricity demand is estimated for the year 2050 (DMRE, 2019).

2.5.8. Green Paper

The Green Paper provides SA's policy of national climate change response. The paper shows SA's commitment to a fair contribution to the stabilisation of global greenhouse gas concentrations in the atmosphere and protecting the nation against climate change impacts. The Green Paper presents the SA Government's vision for an effective climate change response and the long-term transition to a climate-resilient and low-carbon economy and society. SA will be highly impacted in the medium- and long-run should international global warming not be reduced to below 2℃. The predicted temperature increase of around 7℃ after 2050 will result in a drier country with increased evaporation, increased veld fires, extreme floods and droughts, sea-level rise, and mass extinction of endemic plant and animal species (DOE, NCCR, 2015).

Increased atmospheric CO_2 concentrations have been measured at the Global Atmosphere Watch station at Cape Point. Other climate change impacts have been observed around the country such as sea-level rise by 1.87mm/yr in the west coast, 1.47mm/yr along the south coast and 2.74mm/yr along the east coast (DOE, NCCR, 2015).

2.5.9. Climate Change Response Strategy, 2011

South Africa must implement the following strategies to achieve its climate change objective (DOE, NCCR, 2015):

i. Balance mitigation and adaptation to climate change regarding prioritising, resource allocation, focus and action.
ii. Ensure well-informed decisions are made using the development and maintenance of the science-policy interface, knowledge management and dissemination systems.
iii. Short-term prioritisation of adaptation for immediate threats to the health of the country's citizens.
iv. Prioritising mitigation interventions that stimulate new industrial activities, improve efficiency, and encourage competitiveness amongst businesses and industries.
v. Provide a clear understanding of job creation industries, as stipulated in the White Paper.
vi. Increase the ability to measure and predict climate change impacts such as veld fires, droughts, floods and extreme weather events that will impact on people.
vii. Mainstream climate change response from national to local planning levels.

viii. Using incentives and disincentives, by regulation and the use of economic and fiscal measures to promote behaviour change towards a low carbon society and economy.

ix. Understanding the efforts and costs of greenhouse gases reduction, and thus supporting and facilitating the energy, transport, and industrial sectors in their mitigation programmes as Government.

x. Recognising that a more sustainable development path will make the road to resilient climate change easier.

xi. Understanding that measures such as border tax measurements taken by developed countries may affect SA, thus mechanisms to deal with such should be in place.

xii. Acknowledging that SA's response to climate change will affect the African continent, thus the country's response should be aligned with and operates as part of the bigger picture.

2.6. Summary of literature review

An increased number of rural households in South Africa have been electrified in the past 26 years since the end of the apartheid era. This electrification was made possible by various energy policies and the involvement of Eskom in the program. The increased electrification has enabled many rural households to rely less on traditional biomass fuels, though at a slow transition rate. Some rural areas have, however, not had the luxury of receiving free grid-electricity connection and off-grid options had to be explored. Renewable energy solutions such as solar PV (the most common applied technology) have been considered for off-grid connection of rural households. Due to the high initial cost associated with solar PV and low-income-level of many rural households, such rural households cannot afford even the smallest solar-powered device.

Solar PV systems power a small range of utilities, such as lighting, radio and television, which do not produce income for rural households. The cost of solar PV systems and their prices have been dropping, thus many supporters of renewable energy advocate solar PV technology because they contend that the LCOE of solar PV energy has decreased. Energy planning authorities should thus be vigilant in interpreting the values of such benchmark instruments, because while the values have been improved over time, they may still be high relative to traditional power-generating options.

3. RESEARCH METHODOLOGY

3.1. Introduction

This chapter covers the research design, how the data was collected for the objectives and the analysis to address the research problem statement.

3.2. Research design

3.2.1. Research methods

A mixed-methods design was adopted in this research to achieve the set objectives. A mixed-methods approach is a research method which incorporates both qualitative and quantitative research. Quantitative research involves collection and analysis of numerical data from a selected group out of a population, referred to as the sample, in order to measure or quantify the dataset using computational, statistical, and/or mathematical approach (BRM, 2020; Jain & Chetty, 2020). Qualitative research is an exploratory way of obtaining people's viewpoint in a non-quantifiable manner where human emotions, feelings and words are used to gain insight and understanding of their reasoning (Dudovskiy, 2018; BRM, 2020).

3.2.2. Data collection

Table 3.1: Data collection per objective

Objective	Data Collection
Objectives 1 & 2	Questionnaire and interview
Objective 3	Questionnaire/Interview/Supplier

Table 3-1 provides a tabulated summary of the process applied during data collection. A questionnaire was the central tool utilized for the collection of data. Close-ended questions are structured such that the respondent can only choose from a given list of answers, with very minimal elaboration on the answers provided (BRM, 2020). By contrast, open-ended questions allow the respondent to give any answer while enabling open discussion between the interviewer and the respondent (Dudovskiy, 2018; BRM, 2020; Seigle, 2020). The questionnaire was characterised by both closed and open-ended questions. It was divided into three sections, namely, household background, household fuel needs, and household level of knowledge regarding energy efficiency and alternative energy sources.

Households were invited to voluntarily participate in this study; none were forced to. The participants were informed of the terms to part-take in the interviews. The participation of the households' members was on willingness, and a letter of consent was provided for each participant to sign. No appointments were set in advance; the interviewer visited the households unannounced. The responses provided by the households were recorded on paper and later transcribed and stored onto a Microsoft Excel Spread sheet for analysis purpose. The research was conducted in line with the University of Johannesburg Policy on Research Ethics.

Moreover, for all the willing participants, interviews were scheduled, and the questionnaire was used to guide the interview exercise. The interviews were conducted from August 2019 to December 2019. Apart from scheduled interviews, additional data was collected from desktop studies. To achieve Objective 3 (i.e., to determine the cost of an adequate solar PV system for a household of 5 members and 5 rooms) quotations were gathered from various solar system suppliers.

A systematic sampling method was applied to determine and select which households to consider for collection of data. This method enables the researcher to select units at a regular interval and is mostly applied to smaller populations that have minimal variability in the households' demographics and behaviour (BRM, 2020; Jain & Chetty, 2020). The area under study has 261 households (i.e., N=261). The sample size was calculated using the equation 3.1 below by (Stephanie, 2012; Kambule, 2018; Mojosh, 2018) where *n* is the sample size, N is the population size, and e is the level of confidence. In this calculation, a 90% level of confidence (i.e., with an error *e*=10%) was considered, resulting in a sample size of 72. However, the final value was rounded off to the nearest higher 10th value of 80 to make the reading of results convenient, where every third household (Seigle, 2020) was selected (Population Size / Desired Sample Size = Interval).

Equation 3-1: Slovin's formula used for calculating the sample size.

$$n = \frac{N}{(1 + N * e^2)}$$

3.2.3. Data analysis and interpretation

The data collated through questionnaires were analysed using two data analysis software: Statistical Program for Social Science (SPSS) and Microsoft Excel software. The employed software assisted in generating bar graphs, pie charts, and tables as well as to display the collected data conveniently and descriptively. Specifically, content, descriptive, and inferential analyses were undertaken for a better understanding of what the fuel choice trend in the rural households of Atok is, and the factors influencing the decision-making process. Chi-square tests were conducted for different variables. The chi-square test for independence is used to discover whether there is a statistical association between two categorical variables or not (Pallant, 2007). This is achieved by comparing the frequencies of cases found in the various categories from one variable to the different categories in the other variable. From the test results, the main value of interest was Pearson Chi-Square. A chi-square value that makes the test significant needs to be 0.05 (5%) or lower. A significant test means that there is an association/correlation between the 2 variables.

To compare the financial obligations of wood, electricity, and solar PV, the levelized cost of electricity or energy (LCOE)[2], equation 3-2 was used. LCOE sums up all lifetime costs of the system including maintenance, operation, construction, insurance, taxes, and other finances relating to the energy technology as shown in equation 3-2 (Govindan & Shah, 2018; Dincer & Abu-Rayash, 2020). Research that has used the LCOE approach includes Baurzhan & Jenkins (2014), and Irfan (2020).

In this LCOE equation: the investment cost is represented by I_c, the maintenance cost by M_c, the fuel cost by F_c, the year by c, the discounted rate by d, the operational lifespan of technology by n and the amount of electricity produced in kWh by E_c.

Equation 3-2: Levelized cost of electricity or energy formula

$$LCOE = \left(\sum_{c=1}^{n} \frac{I_c + M_c + F_c}{(1+d)^c}\right) / \left(\sum_{c=1}^{n} \frac{E_c}{(1+d)^c}\right)$$

The methodology followed by Tam, *et al.*, (2017) in the life cycle costing of solar PV is highlighted in Figure 3-1 R. In this study, the methodology was adapted with modifications to the lifecycle from 15 years to 20 years and omitting steps 3 and 4. The monthly mean value of solar radiation in Atok was determined from values provided by Matasane (2014). The total daily electricity produced by solar PV systems was determined by multiplying the system's capacity (obtained from system suppliers) and the mean daily solar radiation value. Specific details of solar PV systems such as operating cell temperature, the power ratio of photovoltaic solar systems, type of solar PV system module and radiation value on optimum tilting and orientation were not considered in the calculation. Moreover, the household electricity consumption was calculated by multiplying the power rating of each appliance used, the number of appliances used, and the number of hours each appliance used for daily. Consequently, the researcher was able to determine the sum of all appliances (i.e., load) used to get the total daily household load (*Wh*).

Due to different household appliances and consumption, the average household consumption of 5 household members was used for this study. The cost of a solar PV system including storage was obtained from the suppliers: ArtSolar and SustainableEnergy. The solar PV system cost was dependent on various factors, most of which were provided to the supplier before being provided with a quotation (Tam, et al., 2017):

[2] Which refers to the total cost of energy (U.S. DOE, 2019)

i. Number of panels and location.
ii. Panels' orientation and installation cost.
iii. Government rebates and support schemes type of panels and inverters.
iv. System design and configuration.
v. Transportation cost for equipment and parts.
vi. Removal of trees or other shadings.
vii. Type of roofing, the height of the roof, and site preparation needs.

Maintenance cost was neglected in this study due to its little to no contribution to the total cost. LCOE of both the solar PV system and grid-electricity were calculated using the LCOE equation provided. A comparison of the LCOE of the technologies in the study was conducted, taking into consideration the social and environmental effects of each technology, to determine the best suitable technology.

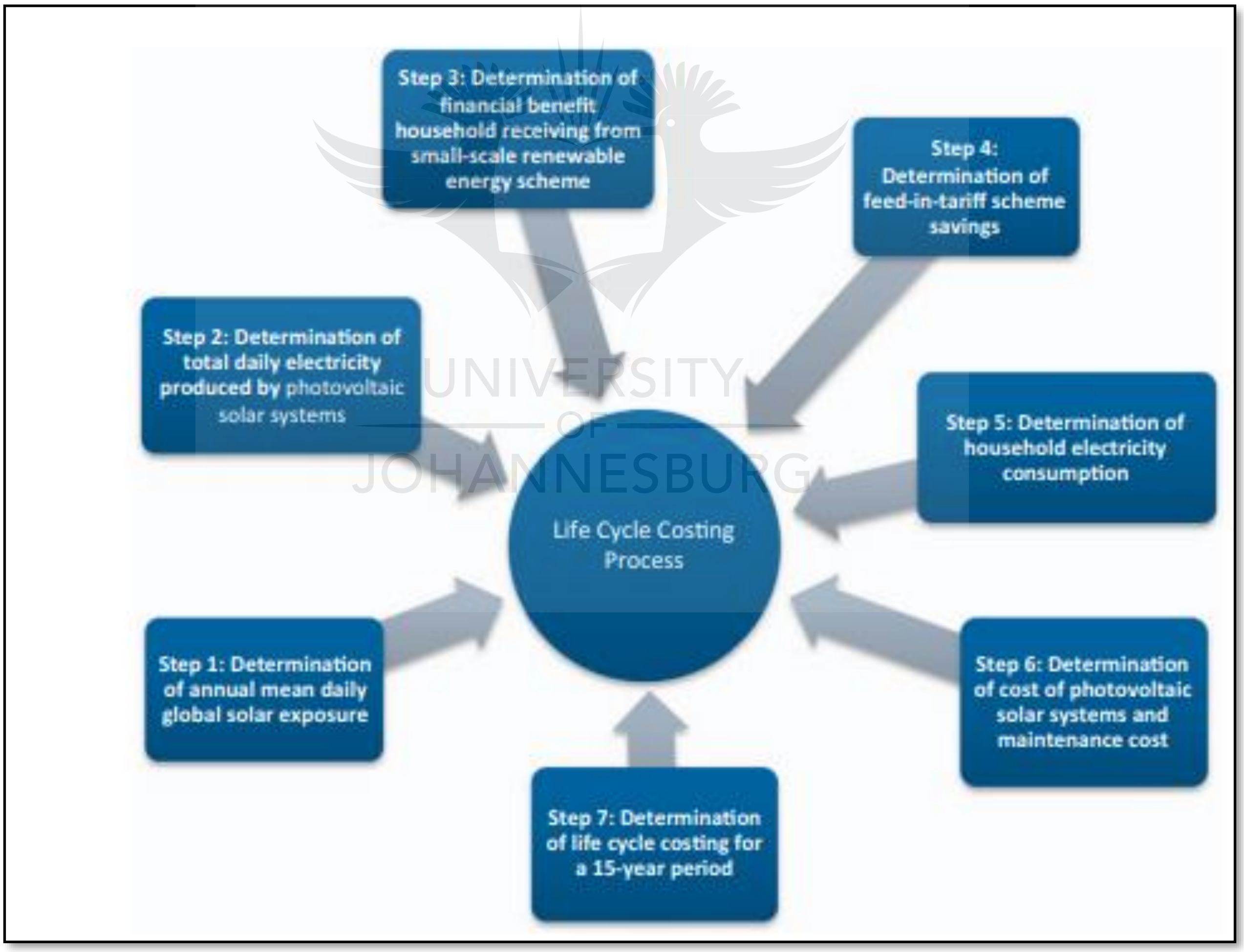

Figure 3.1: Research methodology by Tam *et al.* in measuring the life costing of solar PV in residential dwellings in Australia (Tam, *et al.*, 2017)

4. RESULTS

4.1. Introduction

This chapter presents the results obtained from descriptive statistics. The chapter is divided into two main sections. The first section (4.2) presents the general study household demographics; and the last section provides findings on fuel usage and factors influencing such fuel choice. Section 4.3 further presents the statistical correlation between household demographics and choice of fuel.

4.2. Household demographics and fuel usage

This section covers the frequencies and percentages of household demographics such as homeowners' gender, marital status, age, level of education, household size, and total annual income. Table 4-1 presents the distribution of household heads gender in the study area. Forty-eight (≈60%) out of the sampled 80 households were headed by females.

Table 4.1: Gender of household heads

Gender	Frequency	Percent
Female	48	60.0
Male	32	40.0
Total	**80**	**100.0**

Fewer (44%) household owners are either married or partnered, as opposed to those living without partners (Table 4-2). Household owners' age ranged between 18 and 100, with each of the three age groups (younger than 40, 40 to 50, or 50 and above) contributing just above 30% to the sampled age groups. Table 4-3 depicts the number of households represented according to age groups as categorized. Three categories were identified as follows: category1 (younger than 40), category2 (between 40 and 49) and category3 (50 years old or above). The distribution is nearly equal for all the age groups, with each group contributing just above 30% to the total households. It was found that category 1 was most represented with 29 households.

Table 4.2: Homeowners' marital status

Marital status	Frequency	Percent
Single, Divorced, Widowed & Separated	45	56.3
Married & Partnered	35	43.8
Total	**80**	**100.0**

Table 4.3: Age of homeowners

Age	Frequency	Percent
Younger than 40 years	29	36.3
40-49 years	24	30.0
50 years or older	27	33.8
Total	**80**	**100.0**

The average household size of the sampled households was 5.2 members per household (Table 4-4). The household size ranges from 1 to 15 members, with some 59% of the households ranging between 4 and 6 members. Just above 10% of household owners have some form of higher education, and 59% of the owners never matriculated (Table 4-5).

Table 4.4: Household size

Members of the household	Frequency	Percent
1 to 3	16	20.0
4 to 6	47	58.8
7+	17	21.3
Total	**80**	**100.0**

Table 4.5: Household head's education level

Education level	Frequency	Percent
Up to high school	46	57.5
Matriculated and above	34	42.5
Total	**80**	**100.0**

The distribution of annual income was categorized into 3 (Table 4-6) as follows: category1 (R19 600 or less), category2 (R19 601-R153 800) and category3 (R153 801 or more). These three categories' frequencies are not that far off from each other, however those earning R19 600 or less were more (n=29). Less than 10% of the households have 3 or more employed members (Table 4-7).

Table 4.6: Total annual household income

Total annual income	Frequency	Percent
R19600 or less	29	36.3
R19601-R153800	23	28.8
R153801 or more	28	35.0
Total	**80**	**100.0**

Table 4.7: Number of employed household members

Employed household members	Frequency	Percent
0	25	31.3
1	41	51.3
2	8	10.0
3	4	5.0
4	2	2.5
Total	**80**	**100.0**

Table 4.8: The specific people employed in the households

The person/people employed	N	Percent
HD7.1 Parents	39	43.8%
HD7.2 Eldest sibling	14	15.7%
HD7.3 Other siblings	7	7.9%
HD7.4 Uncle/Aunt	4	4.5%
HD7.5 N/A	25	28.1%
	89	**100.0%**

Table 4-8 presents the data in which members of the households were employed. The participants could choose multiple answers for this question, and the results showed that parents (39) and eldest siblings (14) were the most employed members of many households (Table 4-8).

The number of pensioners in a household increase the total income of the household, thus it was deemed necessary to determine how many pensioners each household had (Table 4-9). 64 of the 80 sampled households had no pensioners in them, while 11 households had only 1 pensioner each, and 5 households had 2 each.

Table 4.9: Number of pensioners per household

Pensioners	Frequency	Percent
0	64	80.0
1	11	13.8
2	5	6.3
Total	**80**	**100.0**

Another potential income generator for mine villages is to rent extra rooms out. It was discovered that only 5 households had rooms they were renting out, 3 of which were renting 2 rooms each, and the other 2 households renting only 1 room. More than 93% of the households were not renting any rooms out.

Table 4.10: Number of rooms rented out

Rooms rented	Frequency	Percent
0	75	93.8
1	2	2.5
2	3	3.8
Total	**80**	**100.0**

4.3. Fuels used and factors influencing the fuel choice.

This section presents the primary fuels used in the households and the factors influencing such choices. The participants mentioned the occasional use of fuels such as paraffin and gas stoves for cooking; however, these will not be discussed due to their insignificant use or contribution to the study. Of the sampled households, 64 had access to electricity. The 16 households with no access to electricity were built after the electrification of the villages took place, nearly 10-15 years ago. These houses relied primarily on firewood for cooking. The primary fuels used for cooking are firewood (n=47) and electricity (n=24) (Figure 4-1).

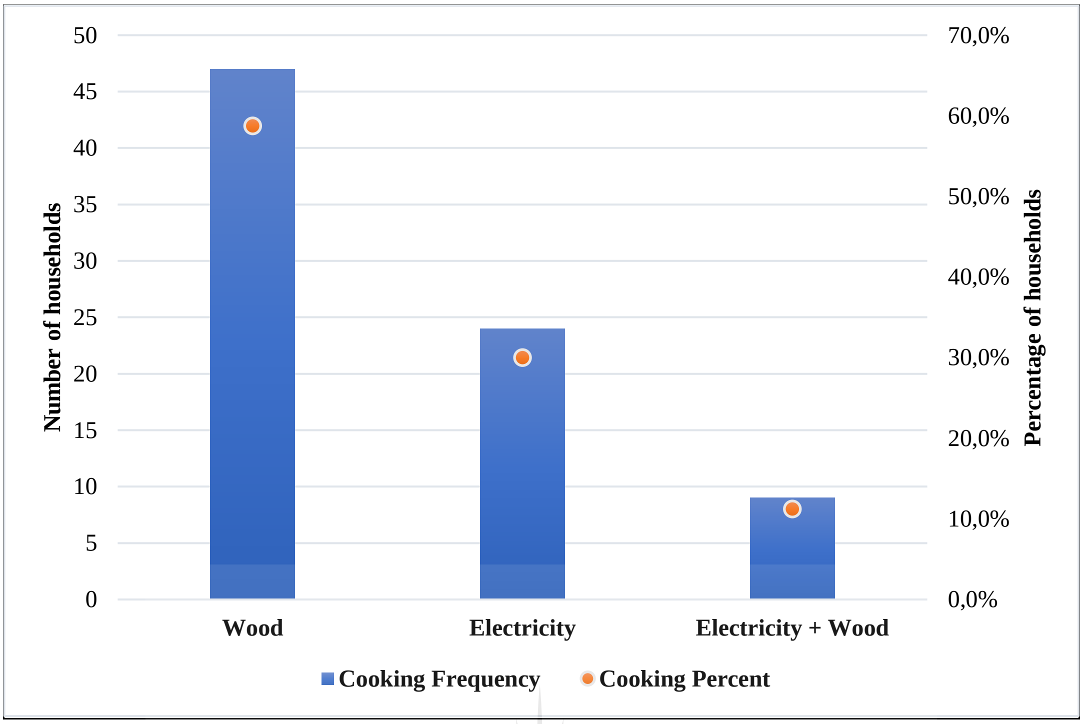

Figure 4.1: Distribution of primary fuels used for cooking in the study area

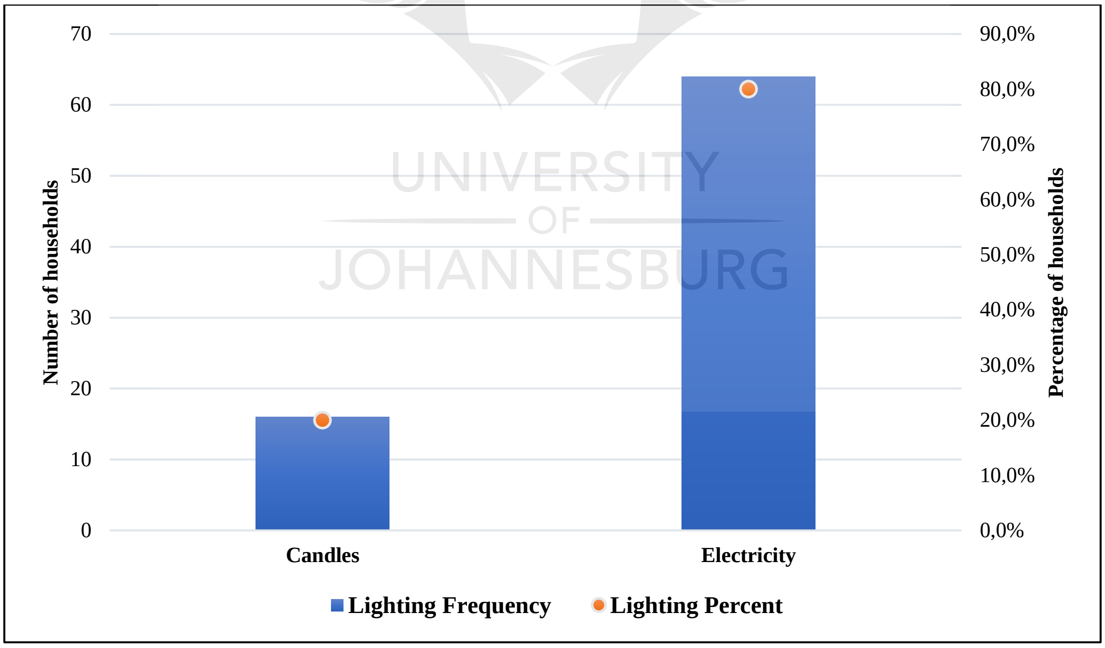

Figure 4.2: Distribution of fuels used for lighting per household

As shown on Figure 4-2, modern electricity is the main source of lighting in all households with such access. Candles are the primary source of lighting for households without electricity. Figure 4-3 also shows that electricity is the main fuel for refrigeration for all households with access to it. Only 34

(≈43%) households had electrical space heating appliances. Figure 4-4 shows that the use of electricity only for space heating was predominant than wood (n=26). The three fuel options identified for water heating were electricity, wood, and combination of wood and electricity in by 33, 29 and 18 households, respectively (Figure 4-5).

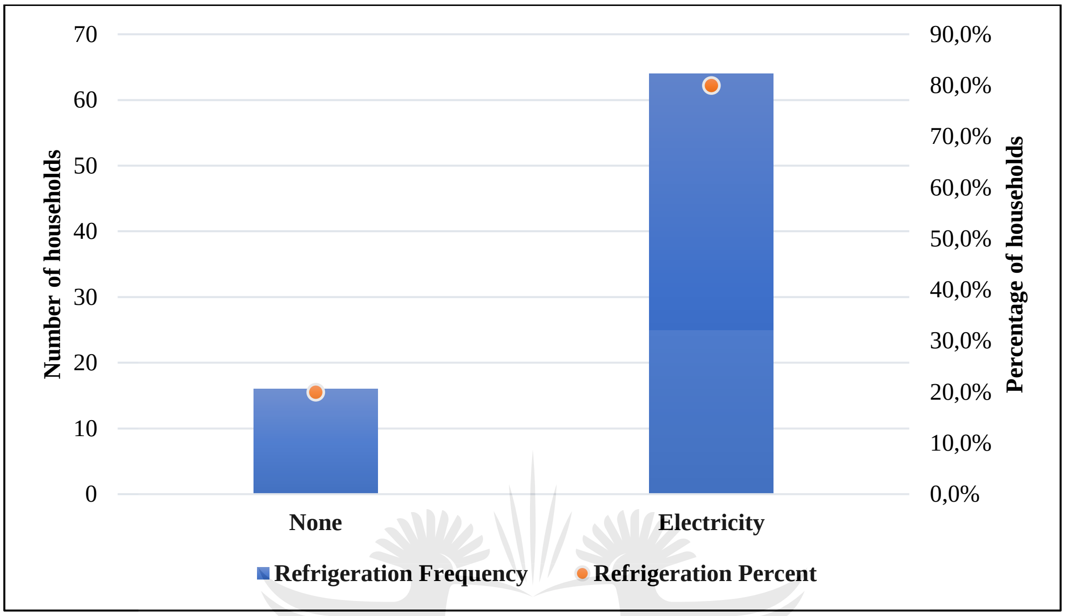

Figure 4.3: Distribution of fuels used for refrigeration per household

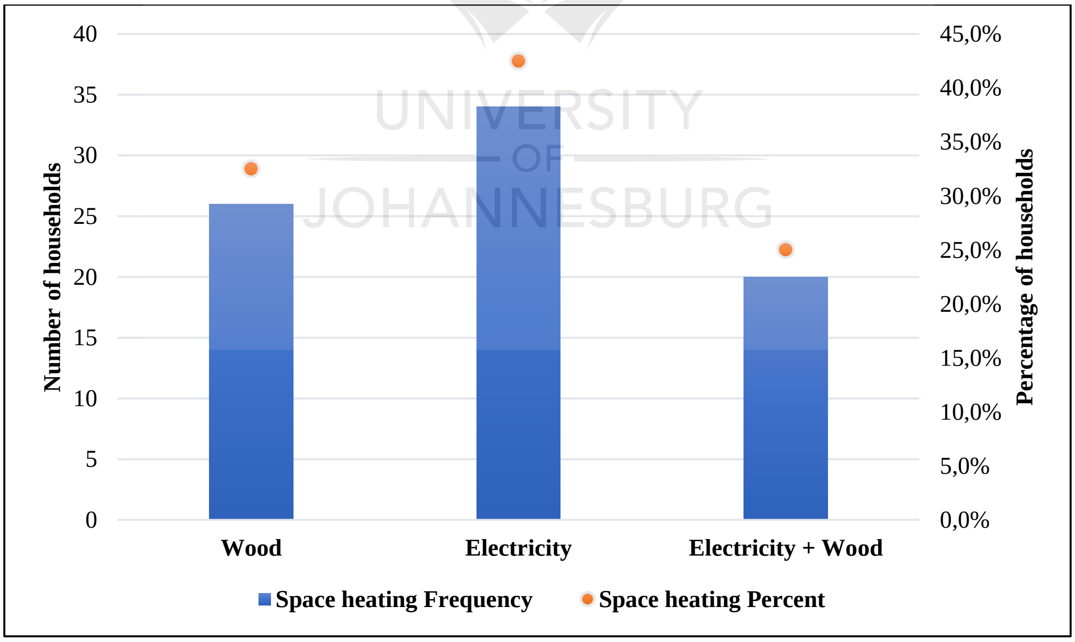

Figure 4.4: Distribution of fuels used for space heating

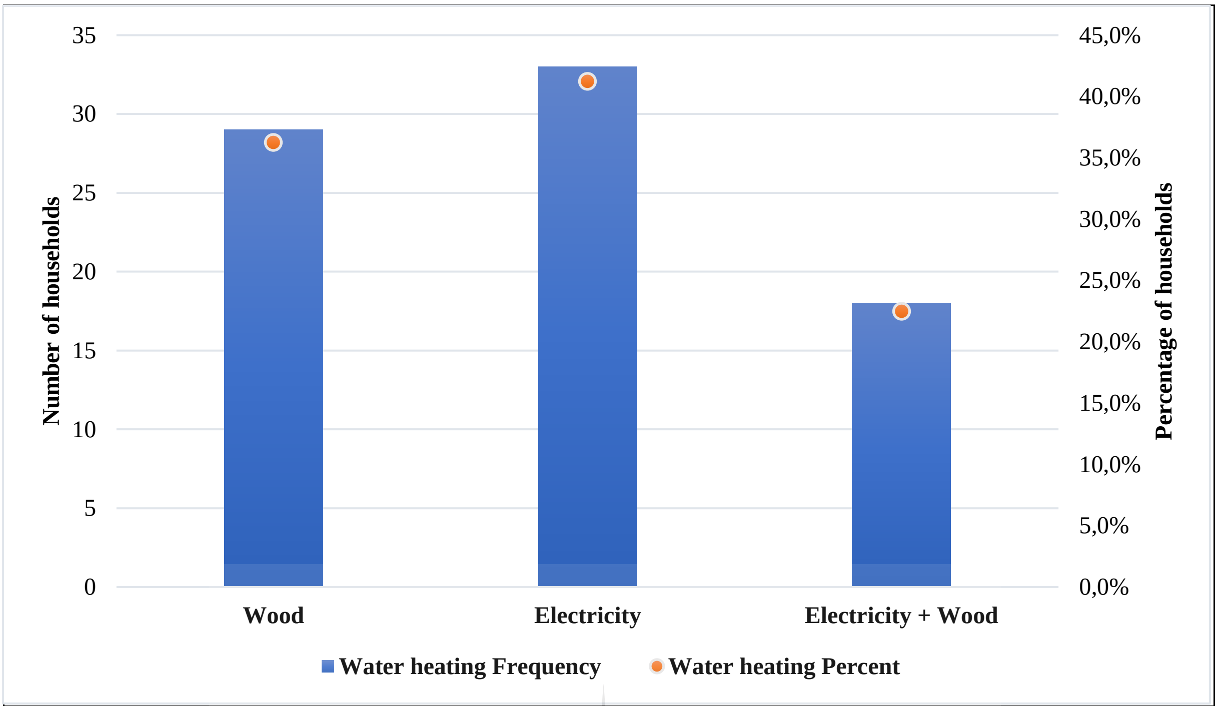

Figure 4.5: Distribution of fuels used for water heating per household

Figure 4-6 indicates that modern electricity is the prevalent energy source for entertainment in all electrified households. The non-electrified households use batteries to power their entertainment. All the households with electricity connection have electrical kettles, irons, and lighting. Only 2 households have geysers. Very few households, less than 20% of the electrified households have washing machines, computers/laptop or even fans. Figure 4-7 presents the number of households that have specific electrical appliances.

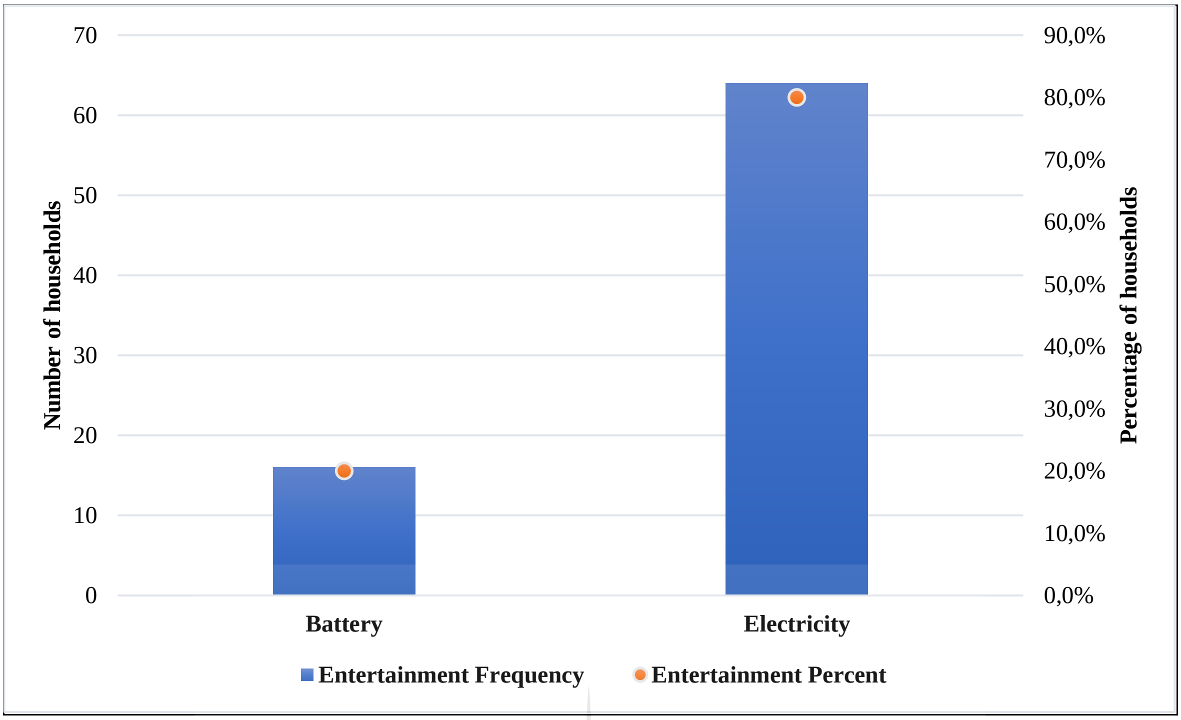

Figure 4.6: Distribution of fuels used for entertainment per household

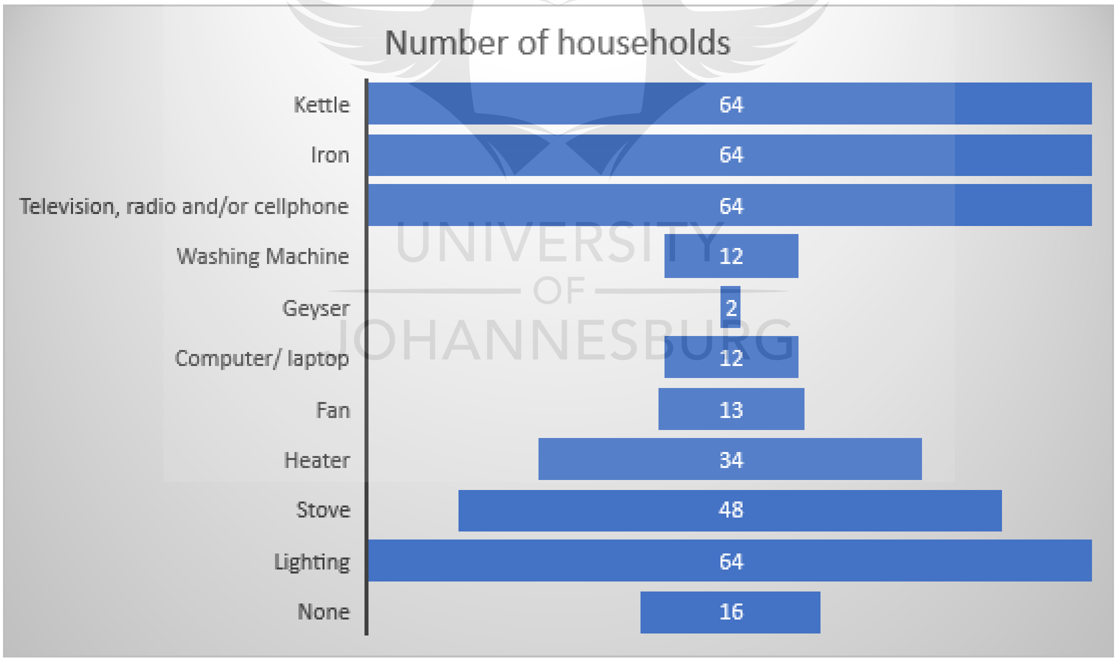

Figure 4.7: Electrical appliances per household

Based on the results provided in figures 4-1 to 4-6, only the factors influencing the use of firewood, or electricity, or both are discussed. The factors influencing fuel choice in other areas have been noted as follows (Davis, 1998; Masera and Kammen, 2000; Cai & Jiang, 2008; Makonese, 2017; Ma & Yu, 2018; Semenya & Machete, 2019):

i. Income and level of wealth
ii. Size of household
iii. Access to electricity
iv. Food Taste
v. Culture and tradition
vi. Information accessibility
vii. Homeowner's age, marital status, gender and level of education
viii. Affordability
ix. Convenience

The study was conducted to test which of the above factors, and other undiscovered factors affect household fuel choice in Mogabane and Maropeng villages. The residents are knowledgeable of other alternative fuels available and would choose cleaner energy such as solar over firewood for most household needs if they could afford solar. 69% of the people know about solar, and all of them mentioned that solar is expensive. It was thus concluded that information accessibility did not affect their fuel choice as there was not enough evidence to suggest otherwise. Due to the contradictory literature on the effect of various household demographics and other fuel choice influencing factors, this section also explores the correlation, if any, between internal household demographics and external factors influencing fuel choice.

4.3.1. Gender

Figure 4-8 indicates that the number of female-headed households (n=29) that use firewood for cooking is far greater than the male-headed households (n=18), as well as the other two fuel options. Electricity appeared to be used by an equal number of households (n=12) for either gender. The use of both electricity and wood is a far less preferred fuel choice for cooking, used by only 2 male-headed and 7 female-headed households. The total number of households using wood for cooking purposes, regardless of the gender of the household head was 47, which is almost twice that of only electricity (n=24), and more than five times (n=9) those using electricity and wood combination.

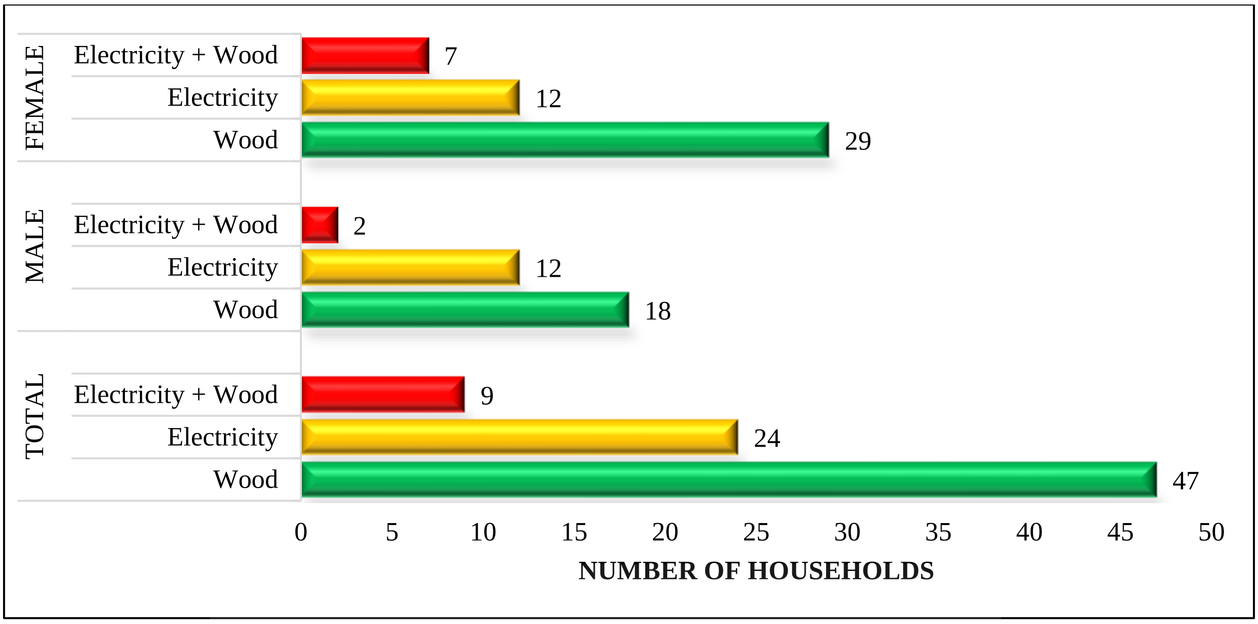

Figure 4.8: Fuel choice for cooking based on the gender of the household head

Figure 4-9 depicts the number of households across gender regarding fuel sources used for space heating in the study area. Across all gender, electricity is predominantly used for space heating although there are slight differences regarding actual frequencies. The number of female-headed (n=11) and male-headed- (n=9) households who use both electricity and wood fuels for space heating is nearly the same. However, the number of female-headed households who rely on either electricity (n=19) or wood (n=18) fuels appears to be higher than is the case in male-headed households. Lastly, when the results are examined in totality, electricity is still the most reported (n=34) source of energy for space heating than others. Similarly, the utilisation of wood fuels is still prevalent amongst (n=26) the total number of all households selected in this study.

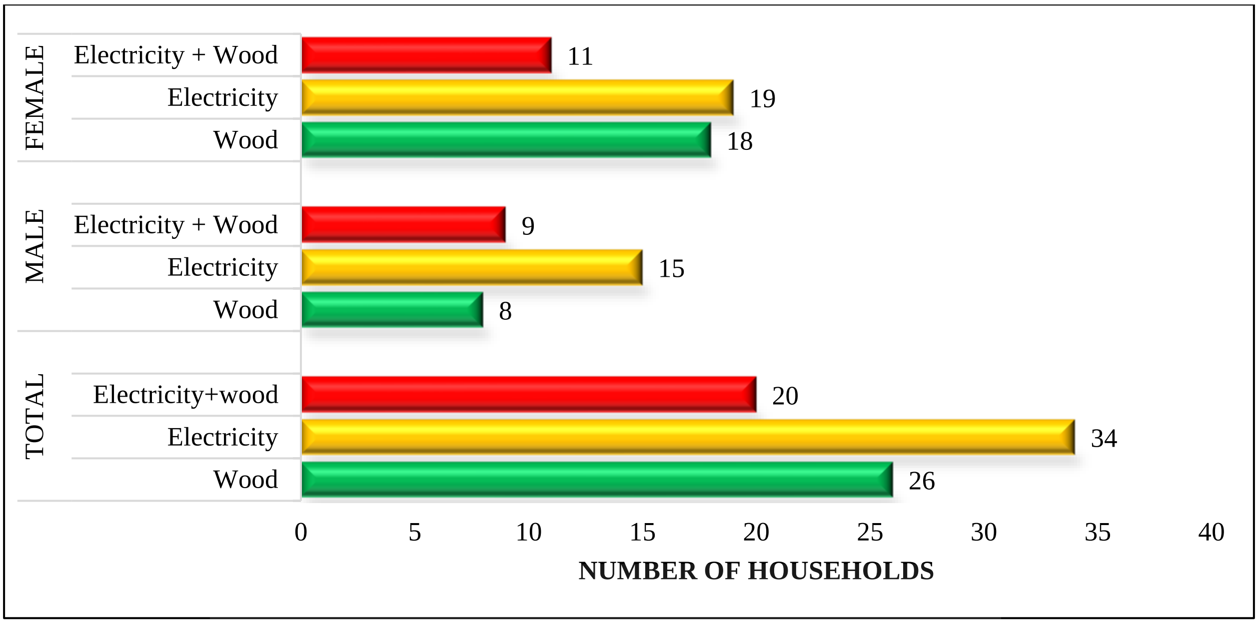

Figure 4.9: Fuel choice for space heating based on the gender of household owner

Figure 4-10 shows the results on the different factors that influence cooking fuel choices based on household gender. Choosing fuel type according to convenience was found to be equally represented amongst households in the study area – respectively 12 responses whether male or female-headed households. Accessibility was found to be a more important determinant of cooking fuel choice amongst female-headed households (n=7) than is the case with male counterparts (n=2). There is a marked difference amongst households in terms of income, whereby there were 10 female-headed households against 6 male-headed households. Furthermore, the influence of food taste featured more prominently amongst female-headed households than is the case in male-headed households. Lastly, when overall patterns were analysed, the influence of both convenience (n=24) and food taste (31) was more pronounced for most households.

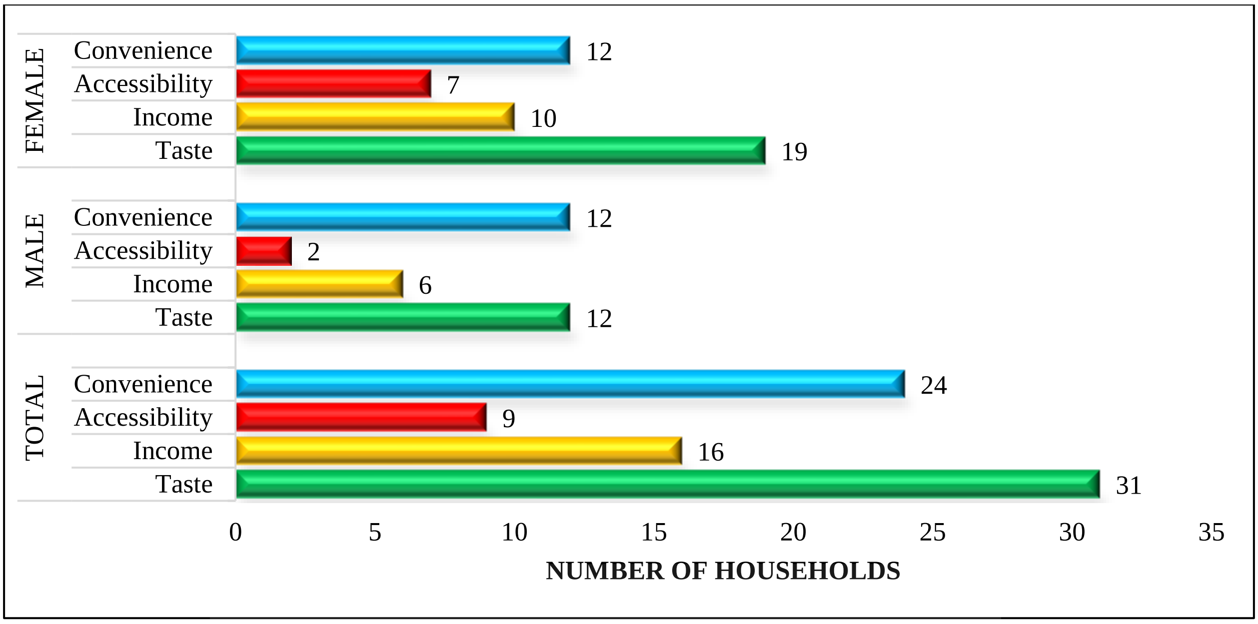

Figure 4.10: Factors influencing cooking fuel choice based on the gender of the household head.

Figure 4-11 displays the results on the factors that influence cooking fuel choices based on household gender. An equal number of male-headed households (n=6) indicated that accessibility, income, and tradition/culture determined their choice of fuel for space heating. Contrary to that, the female-headed households conveyed a much variable trend in the fuel choice determinants for space heating, with the numbers varying from 5, 10 and 17 for tradition/culture, income, and accessibility, respectively. Convenience was found to be nearly similar amongst male-headed (n=14) and female-headed (n=12) households. The combine trend for both genders indicate that convenience (n=30) and accessibility (n=23) had greater influence on the fuel choice for space heating.

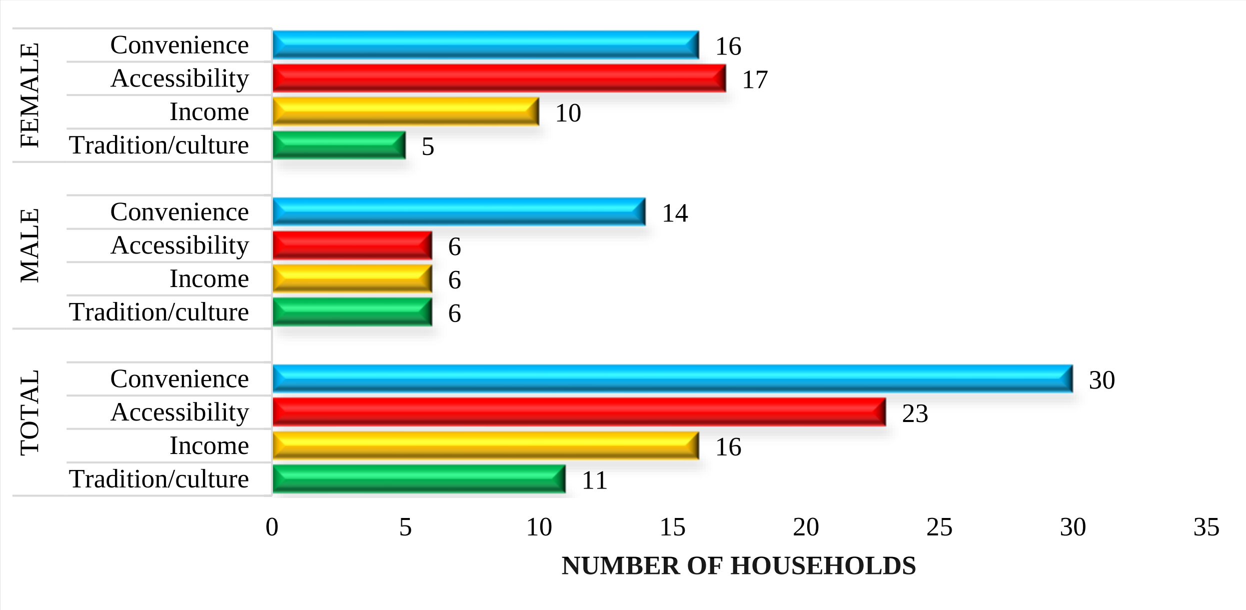

Figure 4.11: Factors influencing space heating fuel choice based on household head's gender

4.3.2. Age

The age of the homeowners was categorised into three: younger than 40, between 40 and 49, and 50 years and older. An equal number of homeowners (n=14) aged between 40 and 49, and those younger than 40 use wood only for cooking. There are more homeowners (n=19) above 50 years of age than those younger, that use only firewood for cooking. There is an equal number of homeowners (n=6) between 40 and 49, and those older than 50 using only electricity for cooking, the number of which is double (n=12) for homeowners younger than 40. A combination of electricity and wood is used for cooking by less than a total of 10 households for all age ranges (Figure 4-12).

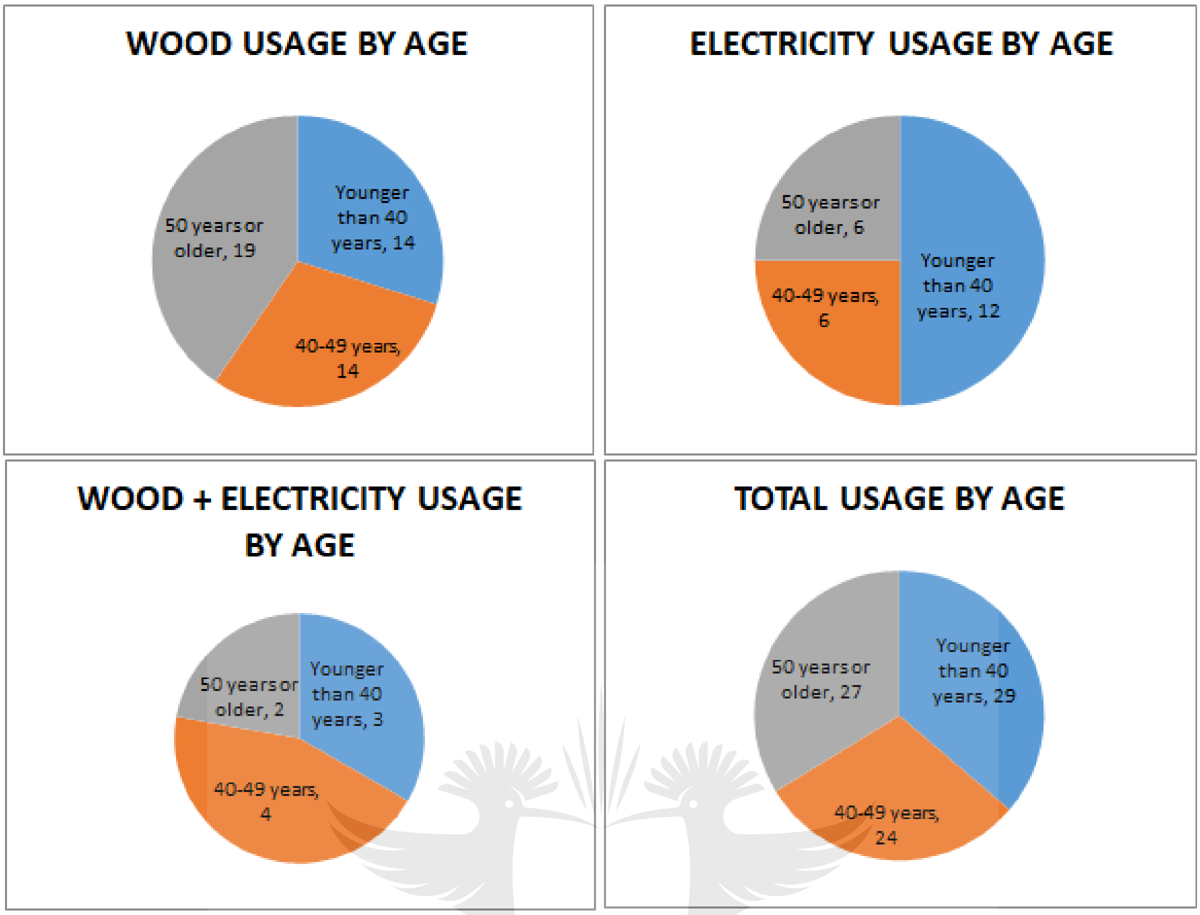

Figure 4.12: Fuel choice for cooking based on homeowner's age

Figure 4-13 reveals the fuel choice for space heating based on the age of the household head. No homeowners younger than 40 used the combination of wood and electricity for space heating. The preference for both wood and electricity in households with owners older than 50 years and those younger than 40 years was recorded at 12 and 8, respectively. There were twice as many (n=16) households' owners older than 50 using electricity only for space heating as there are those aged between 40 and 50 (n=8). Homeowners younger than 40 tend to use wood more for space heating than for cooking, with as many as 19 households, as compared to only 4 and 3 households for homeowners between 40 and 50 years, and those older 50, respectively.

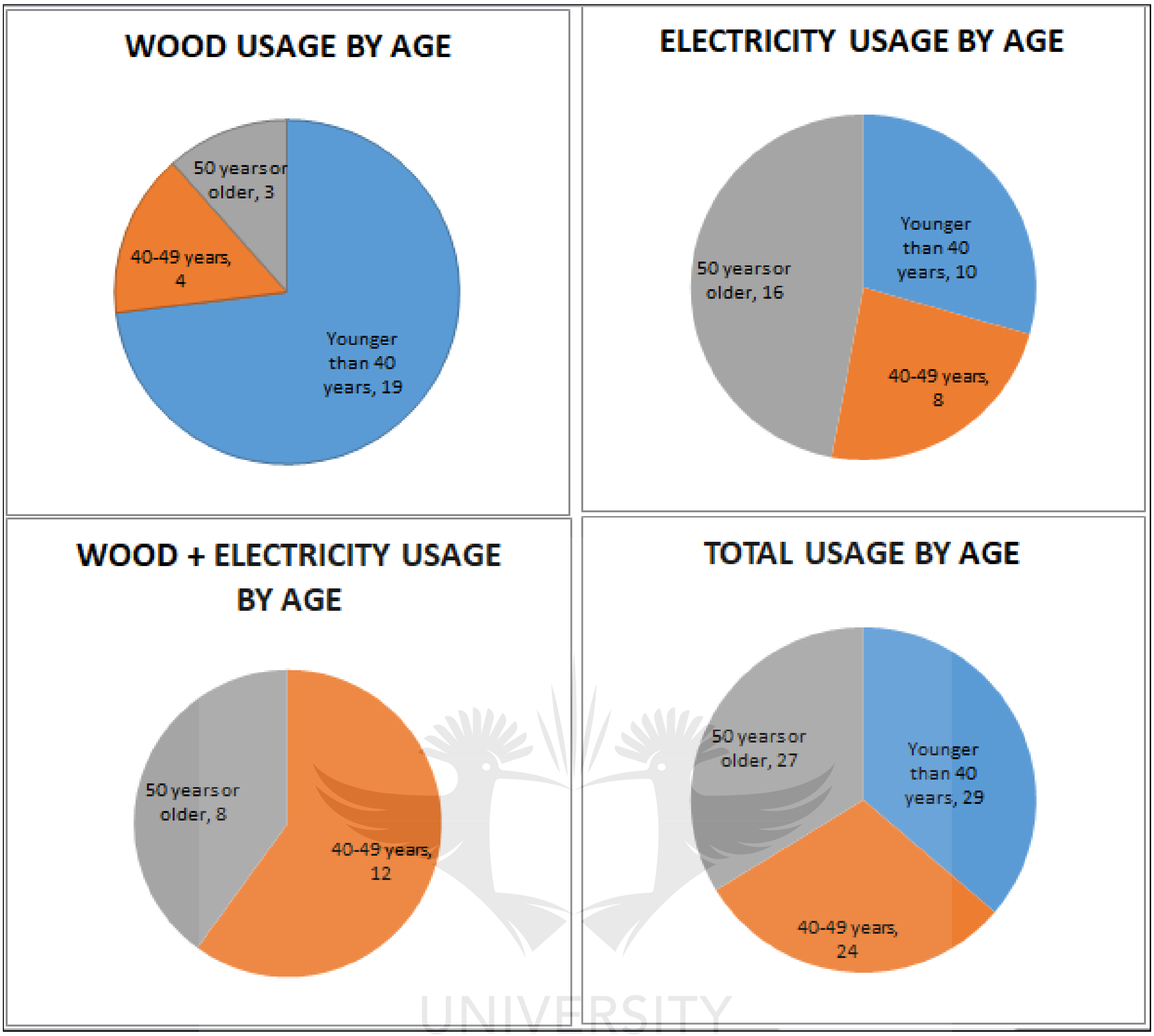

Figure 4.13: Fuel choice for space heating based on age of homeowner

Figure 4-14 depicts influence of taste, income, accessibility, and convenience on the fuel choice for cooking based on the age of the homeowner. Of the 80 households that participated in the study, the influence of taste on the fuel preferred for cooking, 3 was in homeowners younger than 40, 11 in those aged between 40 and 50, with the highest recorded of 17 for those aged older than 50. Quite the opposite was recorded for income as an influential factor to the fuel choice where 11 of the households were aged younger than 40, with 3 for those aged between 40 and 49, and only 2 for homeowners older than 50. Accessibility was recorded to influence 3 of the homeowners younger than 40, 4 of those aged between 40 and 49, and the lowest at 2 for those aged older than 50. An equal number of households (6 each) whose owners are aged between 40 and 49, and those older than 50 was recorded to be influenced by convenience, with twice the number (n=12) for homeowners young than 40.

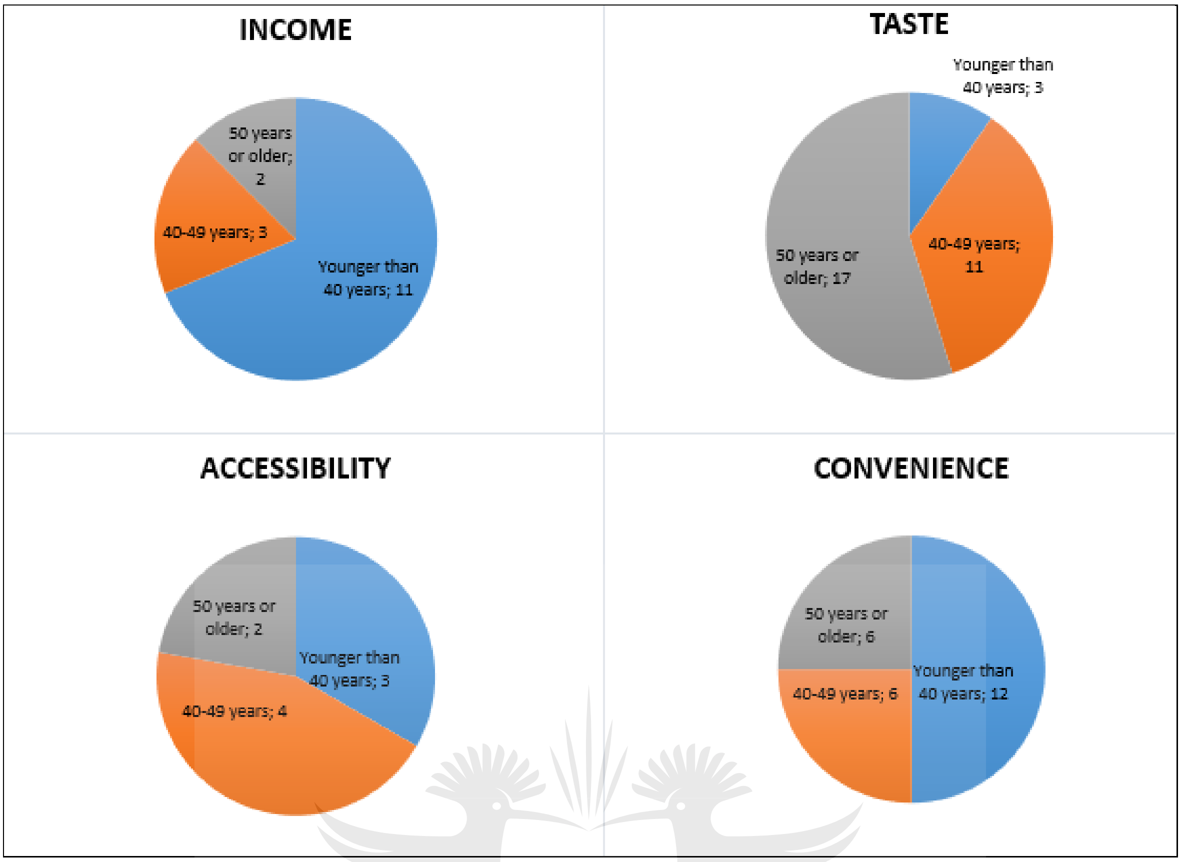

Figure 4.14: Factors influencing fuel preference for cooking based on the household owner's age

Figure 4-15 shows the results on the different factors that influence cooking fuel choices based on household head's age. Choosing fuel type according to tradition/culture was found to be the least represented amongst households, with no responses from homeowners younger than 40, 4 responses by those aged between 40-49 and 7 from those older than 50. Accessibility was found to be a more important determinant of cooking fuel choice amongst female-headed households (n=7) than is the case with male counterparts (n=2). There is a marked difference amongst household heads' age in terms of income, whereby there were 11 homeowners younger than 40, against 3 and 2 for those aged between 40-49 and those older than 50, respectively. Convenience was the most predominant for the oldest homeowners (n=16), followed by the youngest (n=10), and lastly those aged between 40 and 49 (n=4). Overall patterns indicated that the influence of both convenience (n=30) and accessibility (n=23) was more pronounced for most households.

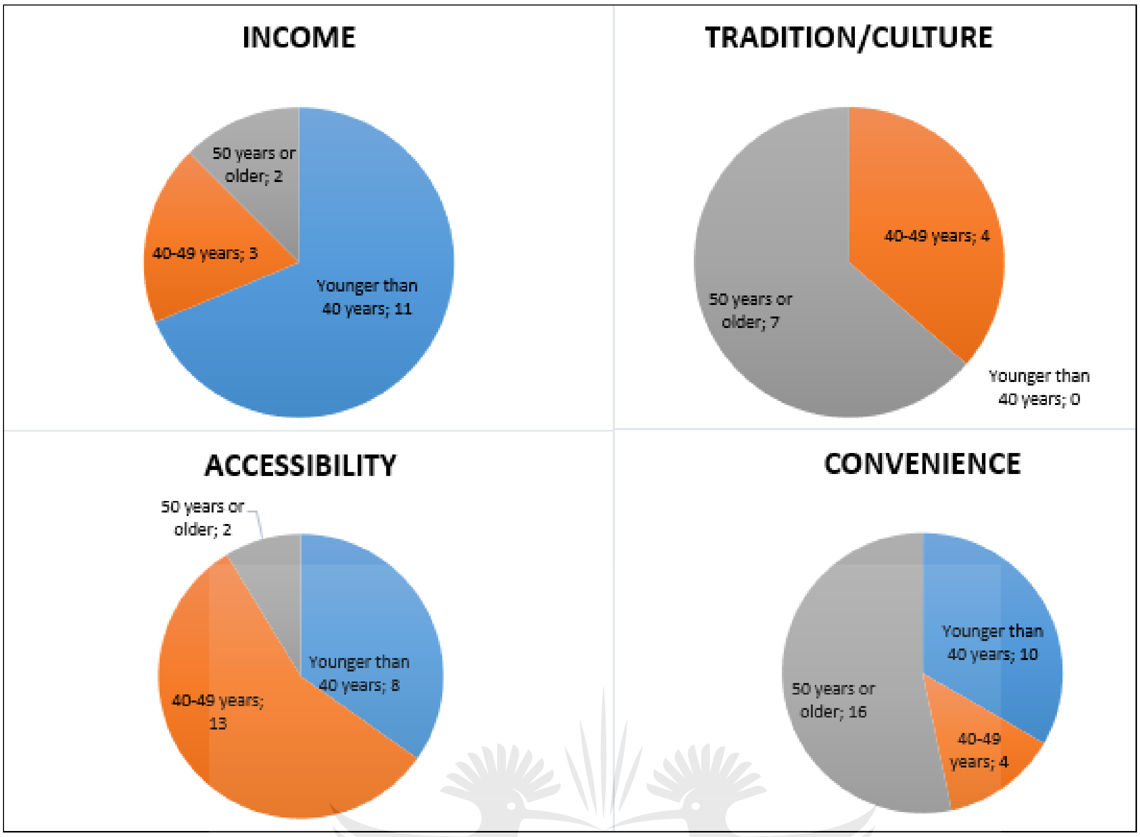

Figure 4.15: Factors influencing fuel preference for space heating based on the household owner's age

Table 4-11 presents the responses by participants, based on their age, to whether they would use electricity exclusively if it was supplied to them for free. 21 homeowners older than 50 answered no, as opposed to only 6 who said yes. On the contrary, 5 homeowners younger than 40 answered no against 24 who said yes, they would. A slight difference in the homeowners aged between 40 and 49 was noted where 9 answered yes and 15 answered no. In total, 39 (≈49%) participants answered yes and 41 (≈51%).

Age		Yes	No	Total

Younger than 40 years	Frequency	24	5	29
	Percent	82,8%	17,2%	100,0%
40-49 years	Frequency	9	15	24
	Percent	37,5%	62,5%	100,0%
50 years or older	Frequency	6	21	27
	Percent	22,2%	77,8%	100,0%
Total	**Frequency**	**39**	**41**	**80**
	Percent	**48,8%**	**51,3%**	**100,0%**

4.3.3. Marital status

Literature suggests that marital status plays a vital role in decision making for a large number of households and as such one of the factors that influence fuel choice. In the study, the marital status used to analyse the fuel choice is segmented into two groups, a group with either gender heading the family alone and a group where the family is headed by both genders. The first segment (category 1) includes single, divorced, widowed, and separated homeowners, and the other segment (category 2) consists of married and partnered homeowners. Figure 4.16 and Figure 4-17 depict the fuel choice by the two-segment for cooking and space heating purposes. Figure 4-16 presents the preferred fuel for cooking according to homeowners' marital status. Wood is the predominant fuel used regardless of the marital status, though there are more of category1 households (n=27) than category2 (n=20). Only 1 household in category 2 uses both electricity and wood, opposed to 8 households in category1. The number of households in category2 (n=14) that use electricity exceeded (not by many units) that in category1 (n=10).

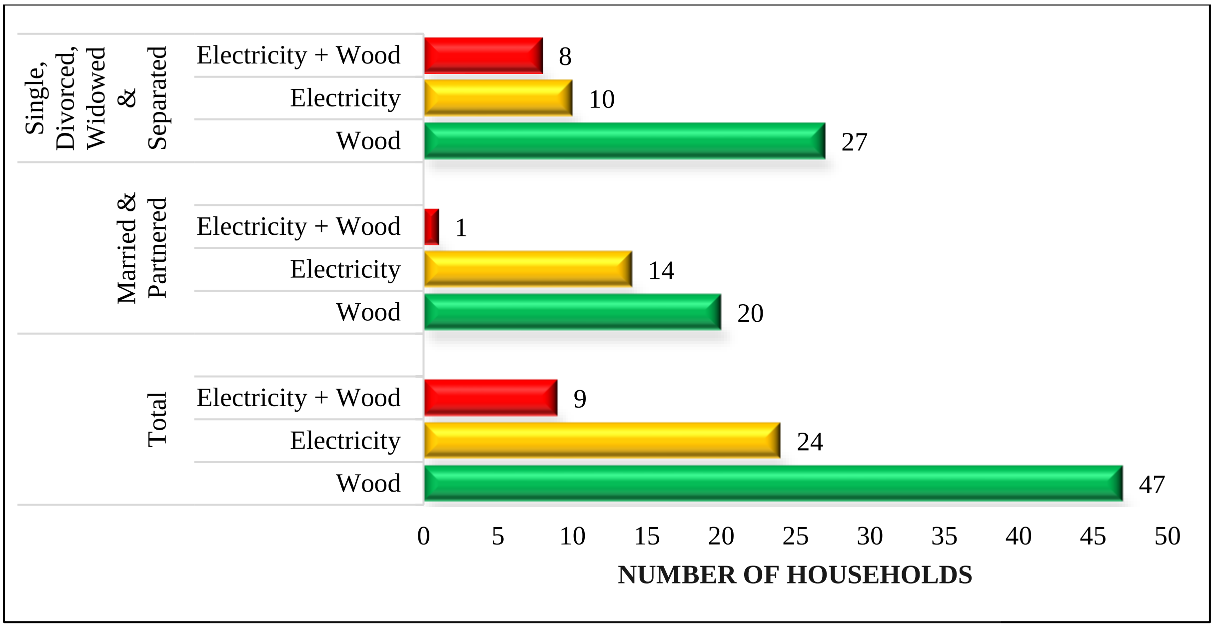

Figure 4.16 : Fuel choice for cooking according to the marital status of homeowner

Figure 4-17 illustrates the number of households using specific fuels to meet their space heating energy needs. Electricity is predominantly used for space heating although there are slight differences regarding actual frequencies. The number of category1 households using electricity or wood are equally represented (n=16), and those who use both electricity and wood fuels for space heating being just below (n=13). The number of category2 households who rely on either electricity (n=18) is the highest of the record. The least recorded households were those of category 2, using both electricity and wood (n=7), and those using only wood (n=10). Analysis of total results reveal electricity as the most reported (n=34) fuel for space heating.

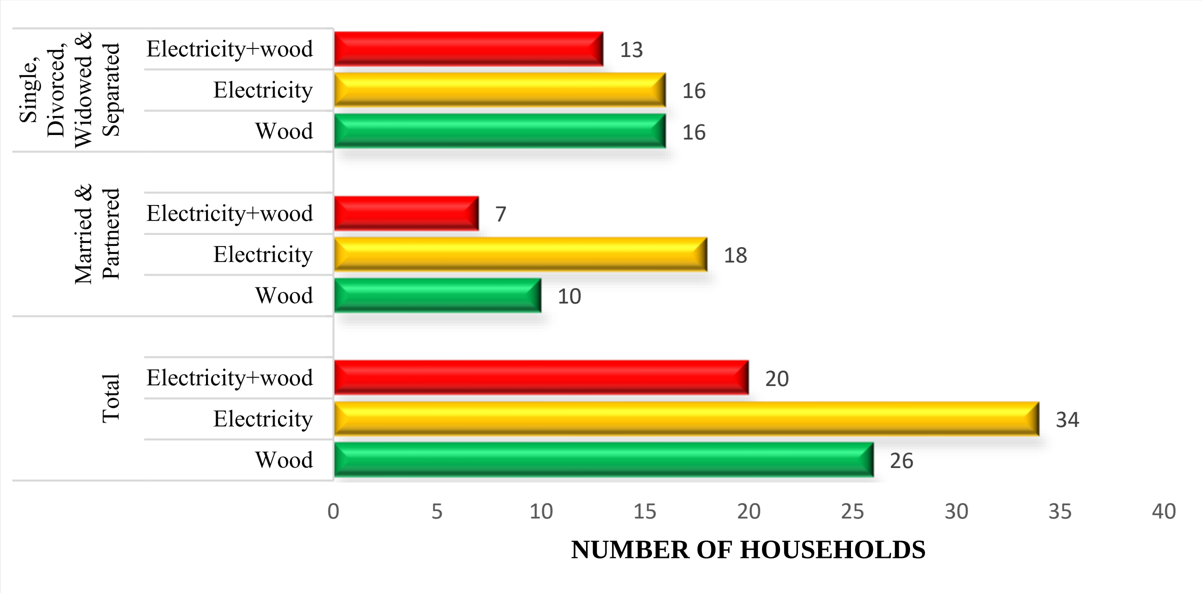

Figure 4.17: Households fuel choice for space heating based on the marital status of the homeowner

Figure 4-18 specify the extent to which convenience, accessibility, income, and tradition/culture influence the fuel choice for cooking. Category1 homeowners appeared to be equally influenced to use certain fuels for cooking by convenience and taste, with 10 households represented for each of the two factors. The effect of taste is the most signified in both categories, though slightly more in category1 (n=17) than in category 2 (n=14). An equal number of category2 are influenced by convenience as they are by taste. A much-distinguished record is that of accessibility where there is only 1 household in category2, against 8 in category1. This also places accessibility as the least influential factor for cooking fuel choice, regardless of the marital status of the homeowner.

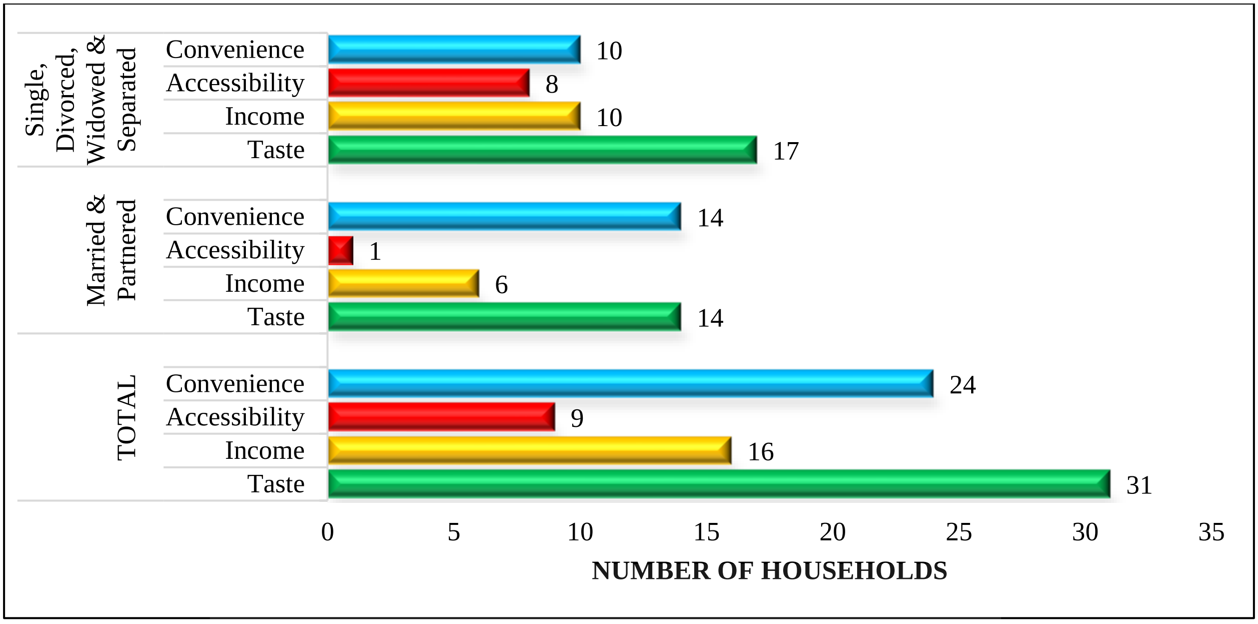

Figure 4.18: Factors influencing cooking fuel choice based on homeowner's marital status

The factors influencing space heating based on the marital status of homeowners are shown in Figure 4-19. The overall trend analysis shows that convenience is the most significant factor (n=30), contributing to space heating fuel choice. A greater influence of convenience is observed for category 2 (n=17) compared to 5, 6, and 7 households for tradition/culture, income and accessibility, respectively. Influence on fuel choice for space heating in category1 is as follows: n=6 for tradition/culture, n=10 for income, n=13 for convenience and n=16 for accessibility.

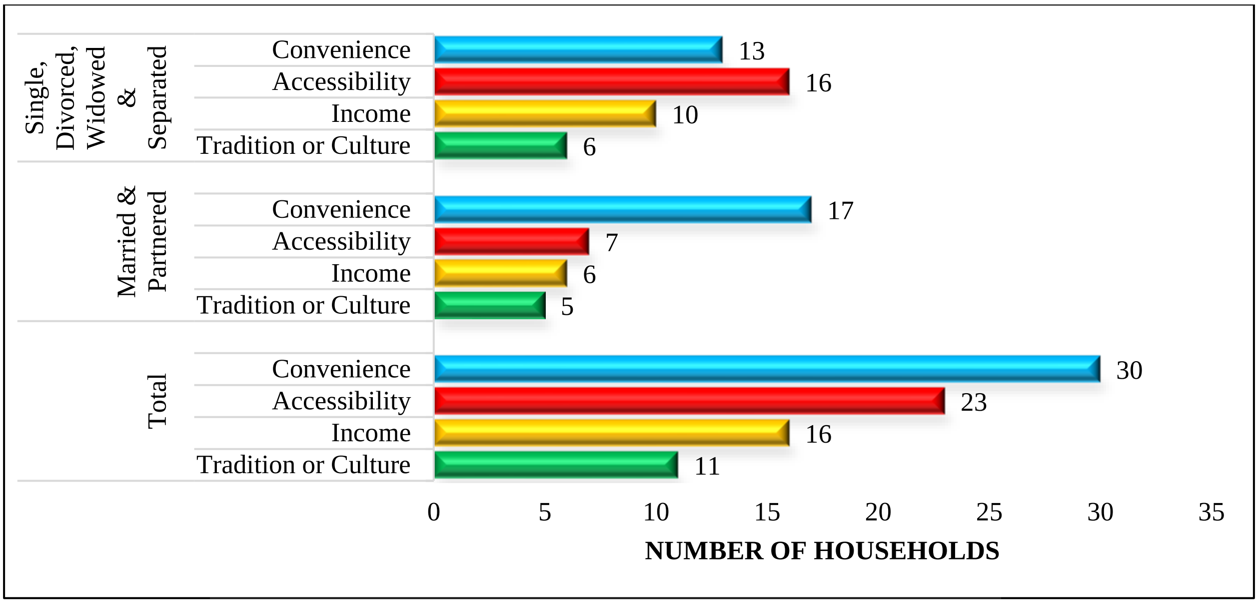

Figure 4.19: Factors influencing space heating fuel choice based on the homeowner's marital status

4.3.4. Household size

The results presented in Figure 4-20 show the proportion of fuels used for cooking in based on the household size. Household sizes are categorized into three for this study according to the number of members staying in the house as follows: category1 (1 to 3), category2 (4 to 6) and category3 (7+). The ratio of electricity- to firewood-using households with more than 7 members is as high as 1:7 (n=2 to n=15). The domination of firewood is observed in the other two categories as well, category1 is represent by 11 households and category 2 by 21. No record of using both electricity and wood was obtained for category3. Expectedly so, the numbers for this fuel were the lowest for category1 (n=2) and category2 (n=7) amongst all the fuels. The use of electricity only n category2 far exceeds that in category 1, with 19 household to just 3, respectively.

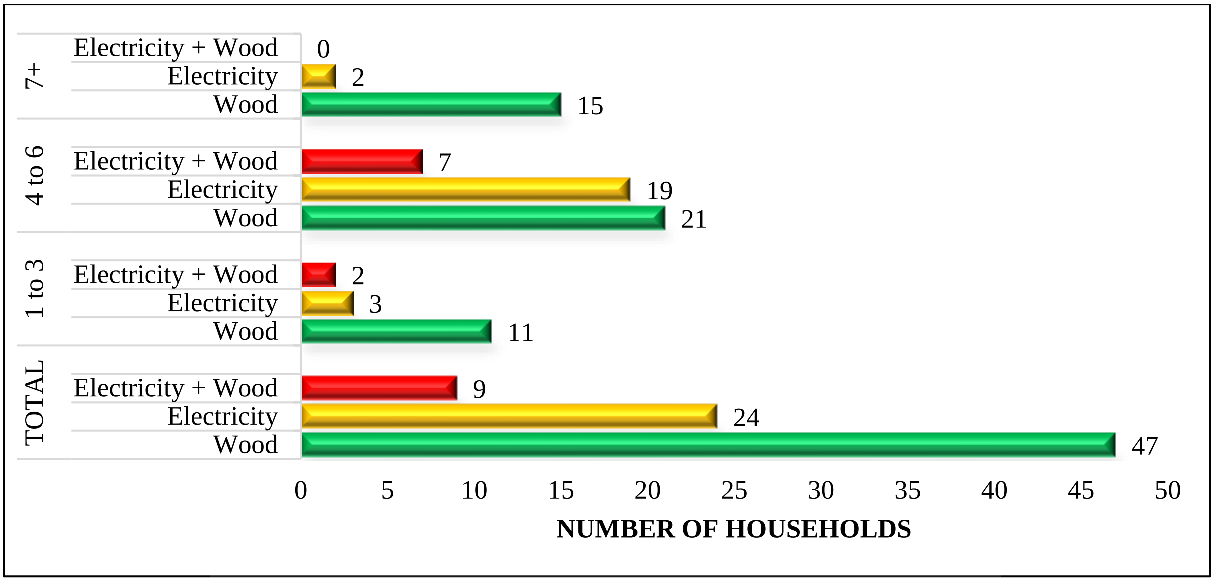

Figure 4.20: Household cooking fuel choice based on household size

Figure 4-21 presents the data for fuel used to meet space heating energy needs based on household size. Category1 has 1, 5, and 10 households representing each of the fuels used, both electricity and wood, electricity only and wood, respectively. In category2, the proportion is somewhat different, where the households using only electricity (n=22) are almost twice as those using either wood only (13) or electricity and wood combination (n=12). Category3 presents its own unique of an equal number of households (n=7) using either electricity only or electricity and wood combination, against only 3 households using wood only. Overall, Electricity only is the predominant fuel choice for space heating based on household size.

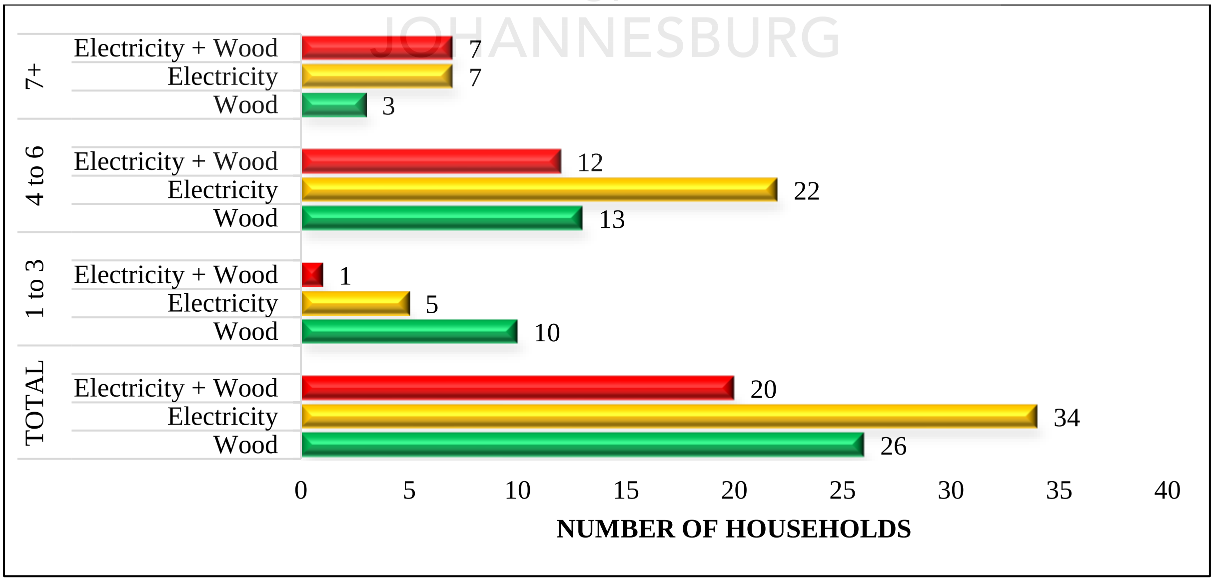

Figure 4.21: Household space heating fuel choice based on the household size

Figure 4-22 shows the influential factors to the fuels used for cooking based on household size. Convenience is without a doubt, the most important in larger households (n=24 in category 3, n=19 in category2 and n=3 in category1). The influence of taste is represented by an equal number of households, n=13, in both category2 and category3. Meanwhile, category1 recorded 5 households for convenience. Accessibility proved to be the least contributing factor for all categories, i.e., category1: n=2, category2: n=7 and category3: n=0. Income had 6 records in category1, 8 in category 2 and 13 in category3.

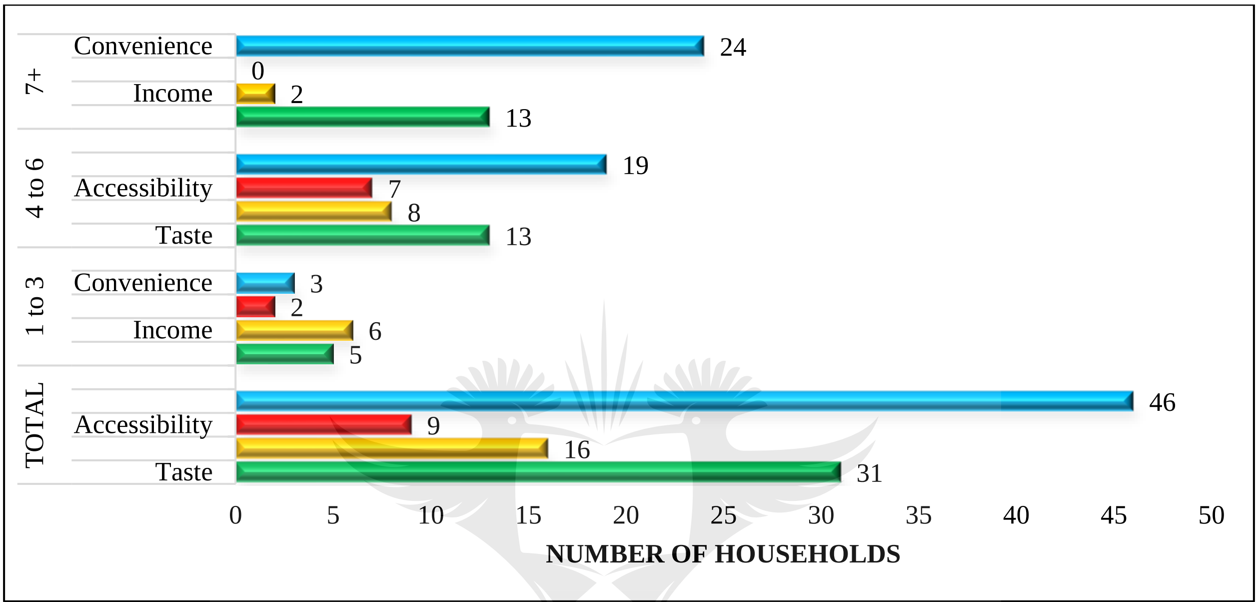

Figure 4.22: Factors influencing fuel preference for cooking based on household size

Figure 4-23 shows the influential factors to the fuels used for space heating based on household size. Overall trend shows the influence in descending order to be convenience (n=30), accessibility (n=23), income (n=16) and tradition/culture (n=11). The same descending order is observed in category2, with the only difference being in the actual frequencies, i.e., n=18, n=15, n=8 and n=6. No records were obtained for tradition/culture in category1 however, 5 households represented category3. An equal number of households (n=5) represented convenience and accessibility in category1, of which were represented by 7 and 3 households in category3, respectively. Fuel choice influenced by income had 6 households in category1 and only 2 in category.

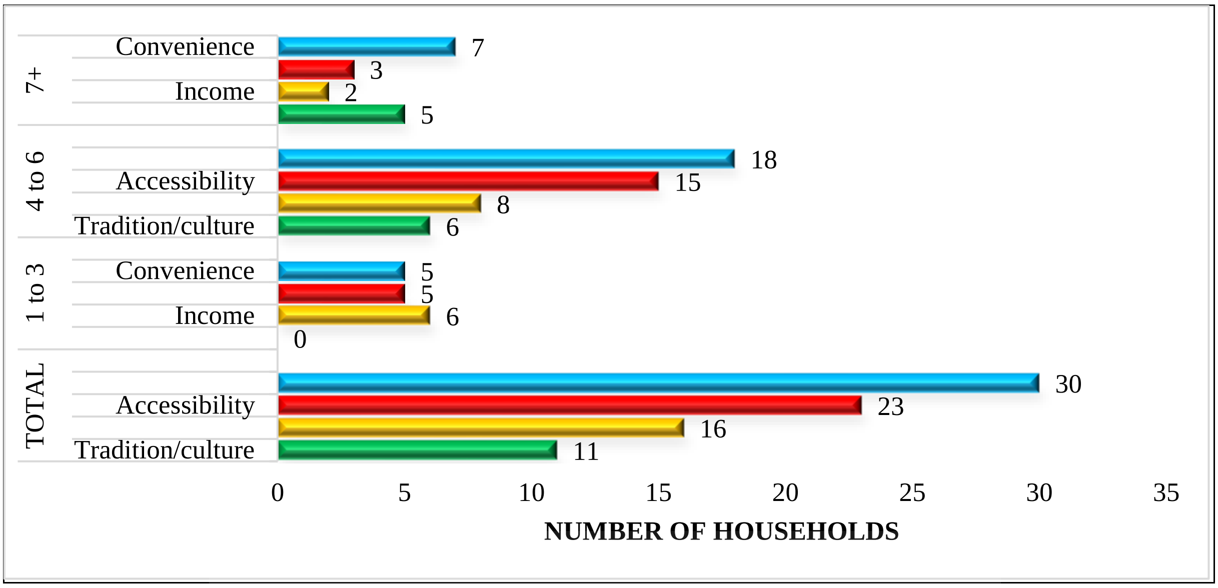

Figure 4.23: Factors influencing fuel choice for space heating based on household size

4.3.5. Education

The choice of fuel for cooking based on the level of education of household heads is presented in Figure 4-24. This figure clearly indicates the extensive use of wood in households where the owner never matriculated (n=34), which is extremely high compared to the other two fuel options namely electricity only (n=8) and combination of electricity and wood (n=4). The results for those that matriculated and/or got higher education level, the use of wood is less dominant (n=13) to electricity only(n=16), but higher than the electricity and wood combination (n=5).

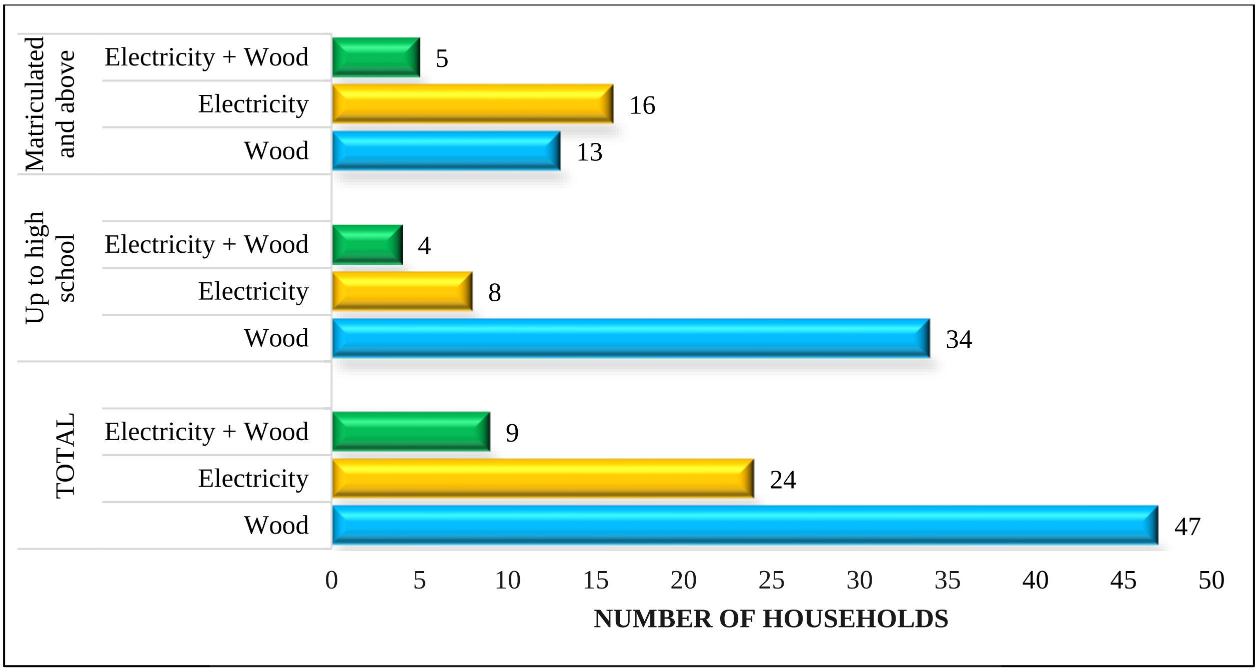

Figure 4.24: Cooking fuel choice based on level of education

In Figure 4-25, the data on fuels used to meet households' space heating energy needs based on level of education are presented. The numbers for the homeowners who never matriculated are somewhat nearly the same, wood represented by 17 households, electricity only by 13, and combination of electricity and wood by 16. However, there is a high number of households using electricity (n=21) for space heating by homeowners that obtained matric or higher education, compared to wood (n=9) and both electricity and wood (n=4).

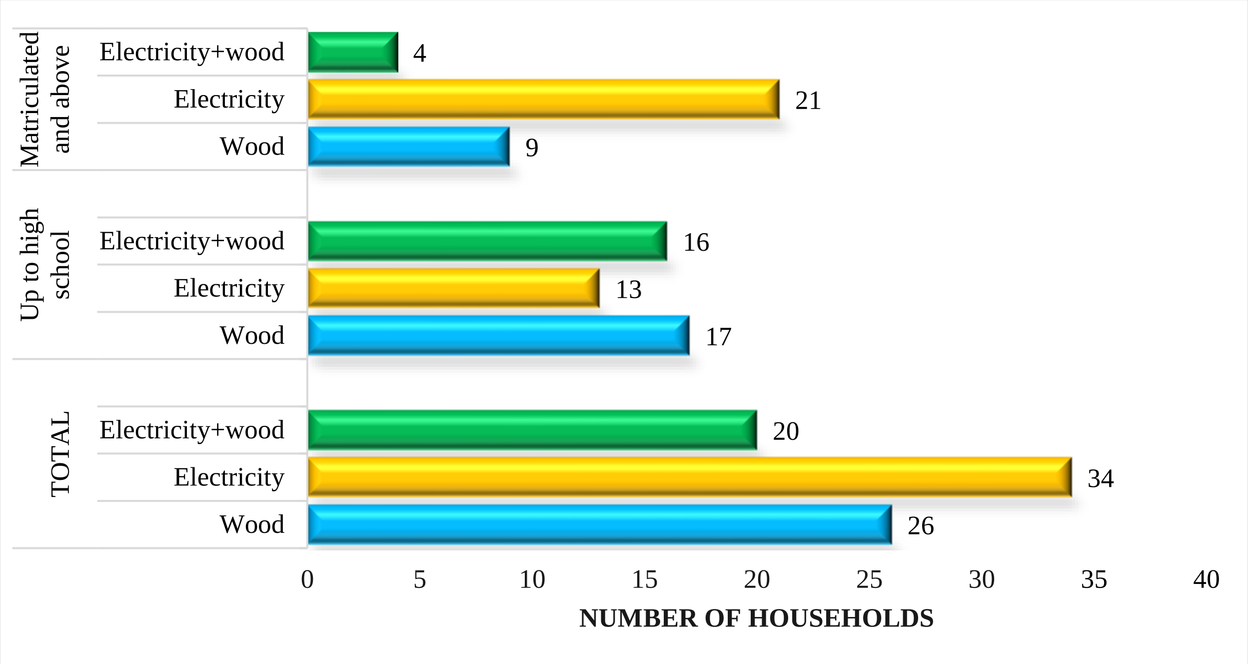

Figure 4.25: Space heating fuel choice based on the level of education.

The extent to which other factors influence the household fuels used for cooking depending on the homeowners' level of education are outlined in Figure 4-26. Twice as many homeowners (n=16) with matric or higher education are influenced by convenience than those without matric (n=8). Homeowners without matric are more influenced by the taste of food (n=21) than income (n=13) and accessibility (n=9). Households with heads that have matriculated or obtained higher education post-matric were represented as follows: accessibility (n=5), income (n=3) and taste (n=10). Taste is the most contributing factor when both education levels are put together (n=31).

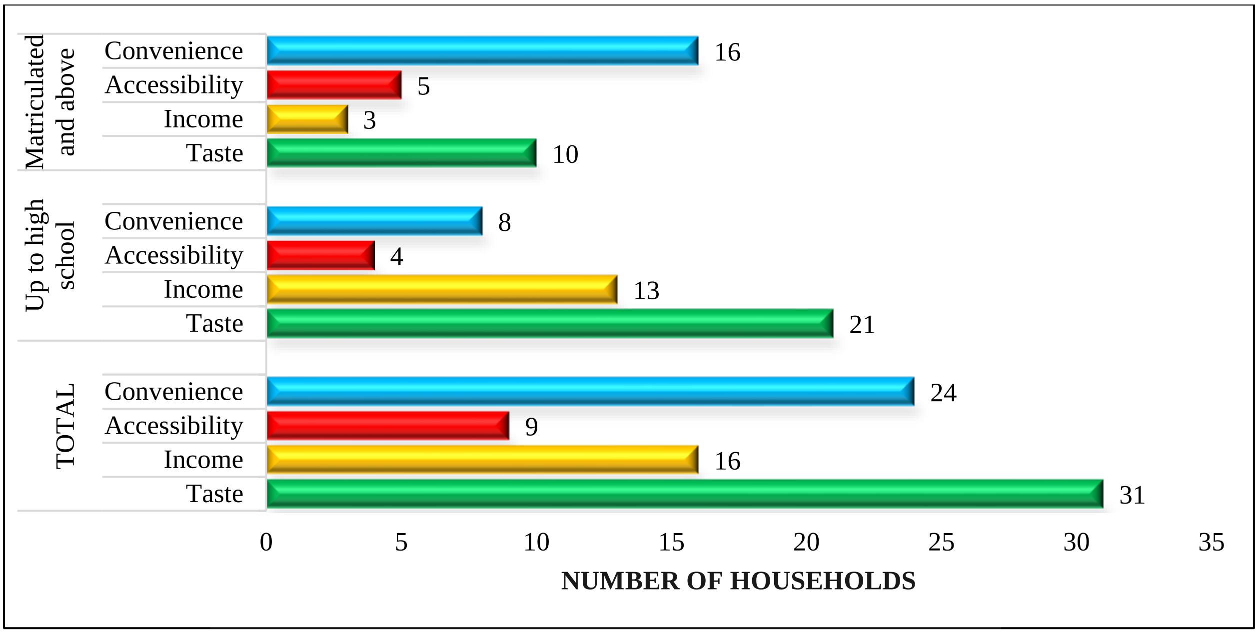

Figure 4.26: Factors influencing fuels used for cooking based on level of education

The influences of convenience, tradition/culture, accessibility, and income on the fuel choice for space heating based on the homeowners' level of education are stipulated in Figure 4-27. Convenience is the leading factor (n=18) in choosing fuel for space heating by homeowners who matriculated or obtained higher qualification. There are 10 households in this education level category that made fuel choice based on accessibility, and an equal number of 3 each that based their choice on income and tradition/culture. For homeowners that never matriculated, accessibility and income are leading with 13 households each, followed by 12 households influenced by convenience and lastly tradition/culture with just 8.

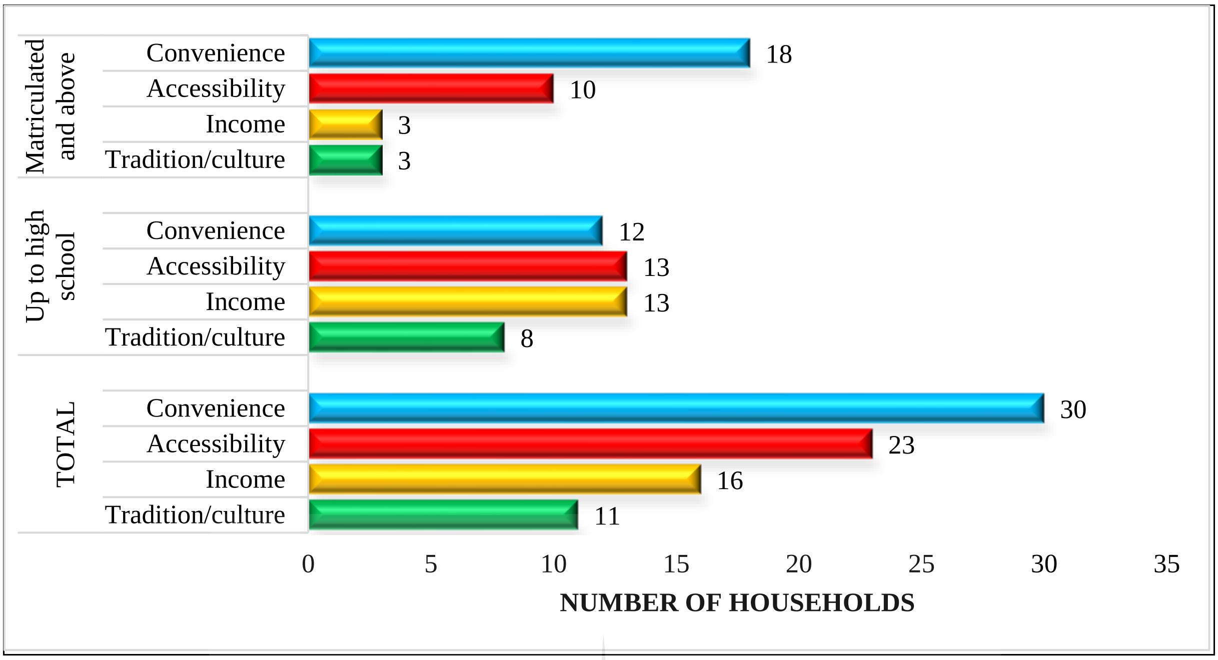

Figure 4.27: Factors influencing fuels used for space heating based on the level of education

Figure 4-28 presents the responses about the participants' knowledge of free basic electricity, in relation to their level of education. In total 72 (≈90%) participants were not aware of FBE, across all education levels, made up of 43 (≈54%) homeowners without matric and 29 (≈36%) with matric or higher education. The remaining 8 households indicated that that they were aware of the FBE but not receiving it, of which 5 were homeowners with matric and 3 those without.

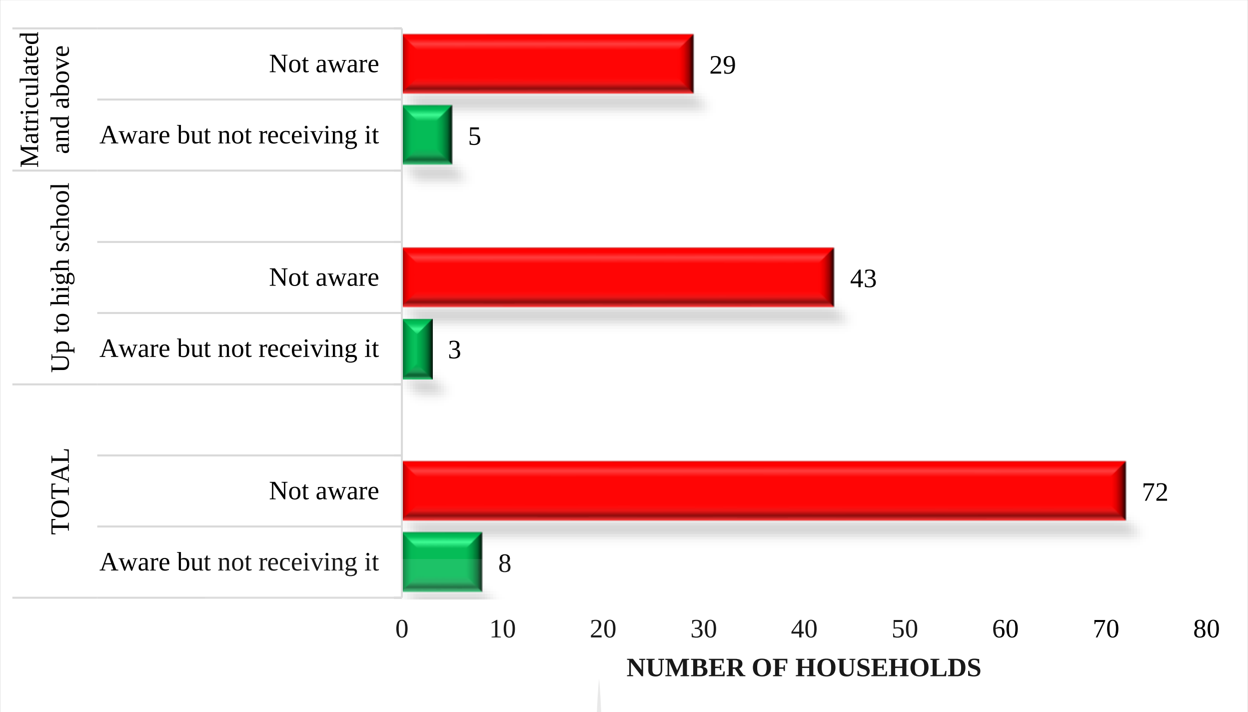

Figure 4.28: Knowledge of free basic electricity

4.3.6. Income

Figure 4-29 presents fuel choice for cooking based on total annual household income. There are 3 income brackets specified for this study as follows: low-income (R19 600 or less), middle-income (R19 601-R153 800) and high-income (153 801 or more). Wood is the predominant fuel choice for cooking in low-income (n=23) and middle-income (n=15) households. The other two fuels are equally represented with 3 households each per fuel in low-income households. There are 6 and 2 households using electricity and combination of electricity and wood, respectively in middle-income households. Contrary to these results are those in high-income households where electricity is the leading fuel (n=15), followed by wood (n=9) and the combination of electricity and wood (n=5).

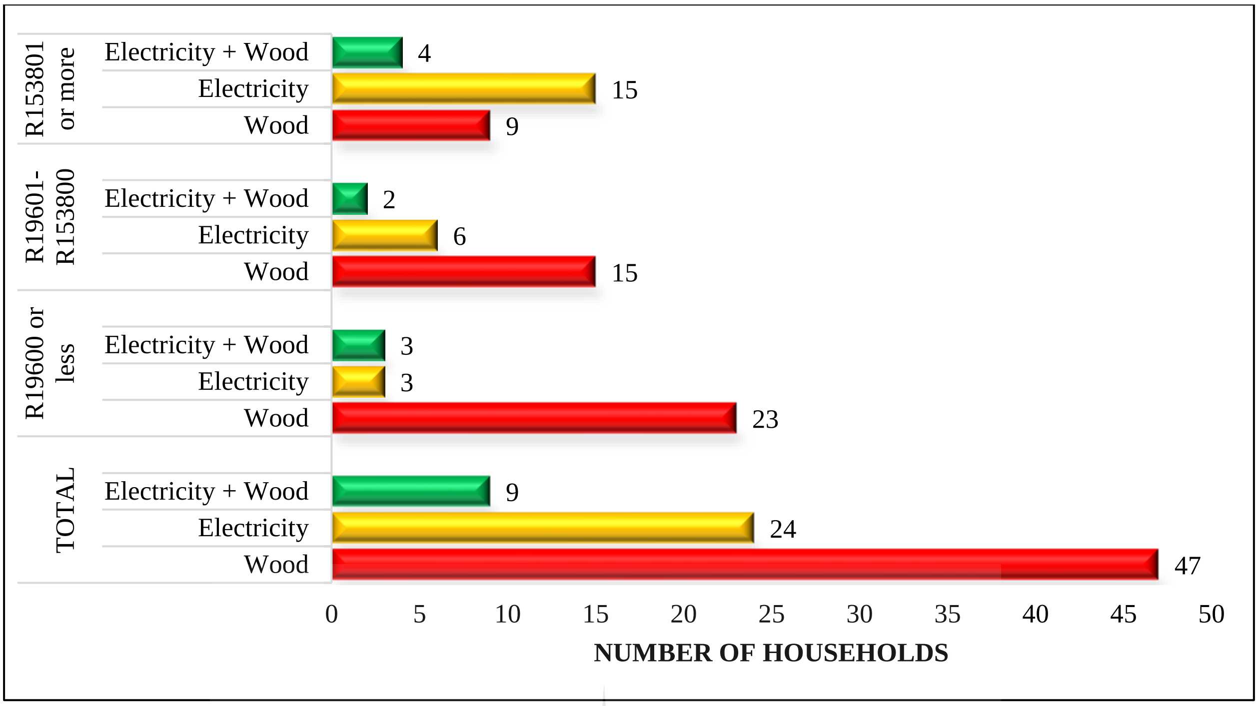

Figure 4.29: Fuel choice for cooking as per total annual household income range

Figure 4-30 outlines the fuels used for space heating based on total annual household income. The number of households using different fuels (i.e., electricity and/or wood) is as good as the same in middle-income households, with electricity only and wood only being used by 8 households each, and their combination by 7 households. Electricity dominates in high-income households with 20 households, followed by 4 households each for the other two fuels. Low-income households have a high representation for wood (n=14), followed by a combination of electricity and wood with 9 households, and lastly the least used fuel being electricity only (n=6).

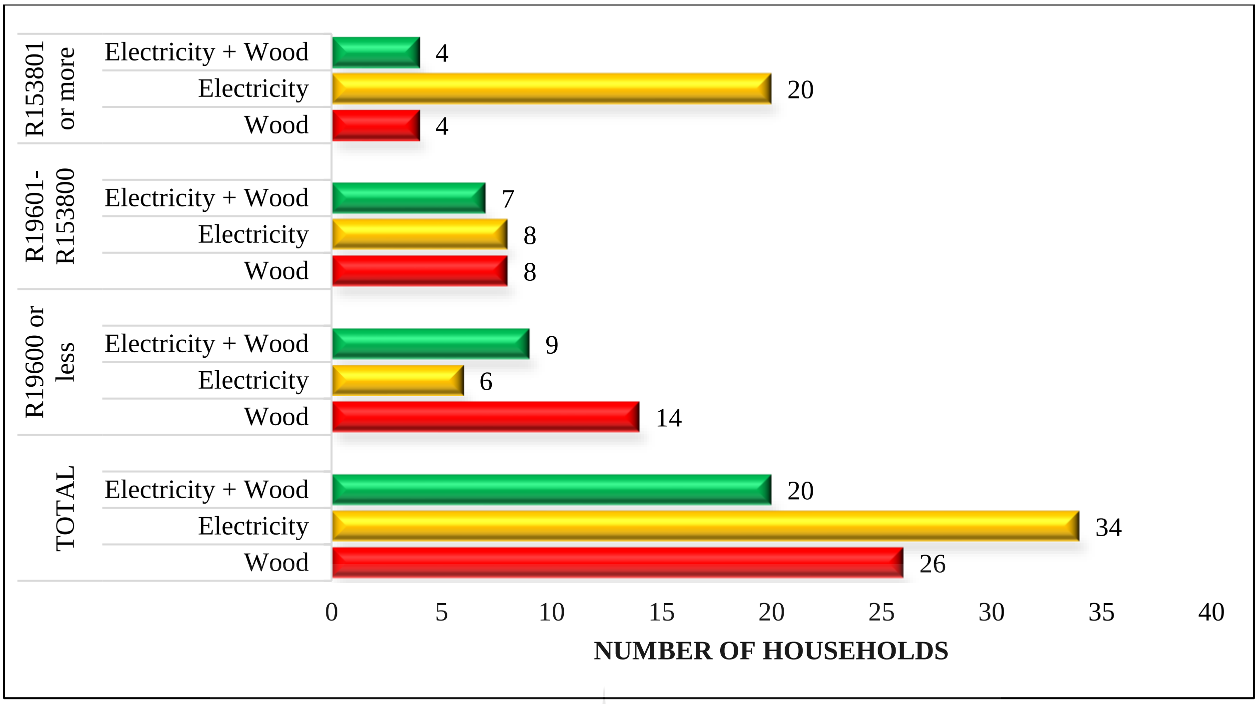

Figure 4.30: Fuels used for space heating based on total annual household income

Figure 4-31 indicates the factors that influence fuel choice for cooking based on the households' income category. For high-income earners, convenience leads fuel choice making decision with 15 households, followed by taste with 8, accessibility with 4 and lastly 1 household influenced by income. Middle-income households are nearly equally represented with 6, 7, and 8 for convenience, income, and taste, respectively. Meanwhile, the influence of accessibility was noted in just 2 households. A notable difference in the results for low-income households is shown where taste is the most influential factor (n=15), followed by income (n=8) and equal number of households recorded for convenience and accessibility (n=3).

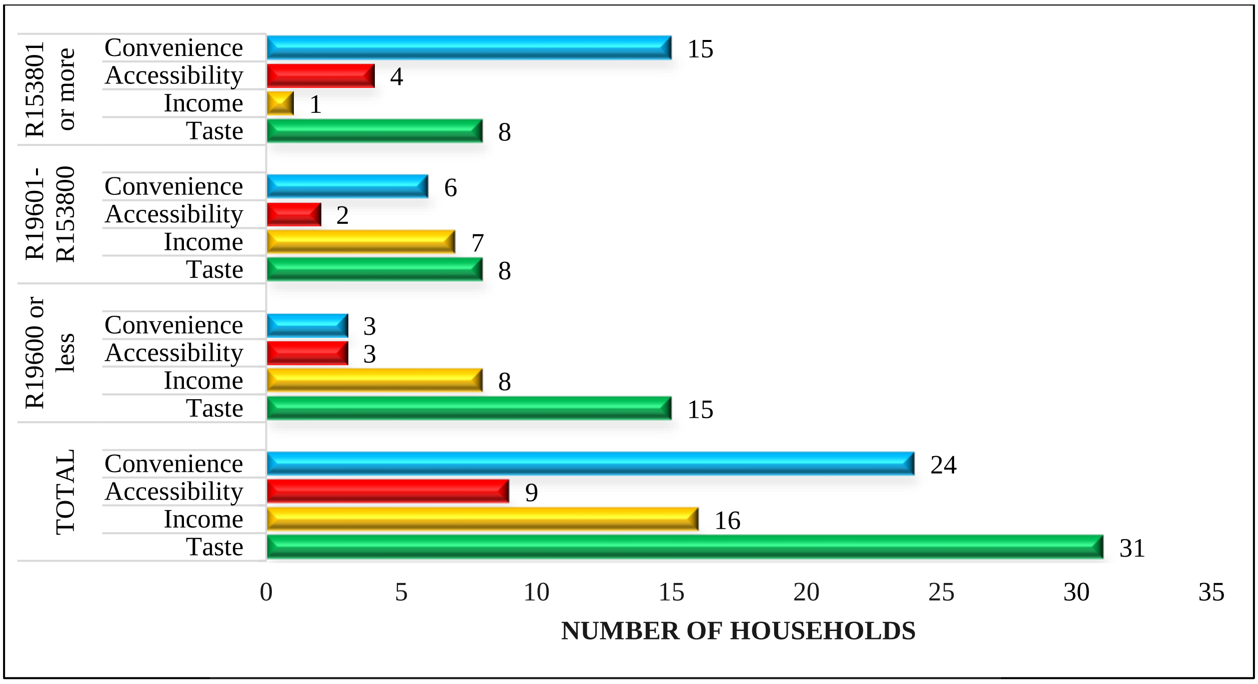

Figure 4.31: Factors influencing fuel choice for cooking based on the total annual household income

Figure 4-32 indicates the factors that influence fuel choice for space heating based on the households' income category. Of the 28 (≈35%) households in the high-income range, 18 reported their fuel choice for space heating to be influenced by convenience, as opposed to 6 in each of the other two income ranges. However, accessibility was recorded as the most influential factor in the low-income range with 13 households, against 5 households each in the other two income ranges. The influence of income recorded the lowest number of households for high-income earners (n=1), 7 for middle-income range and 8 in the lowest income range. Taste/culture was the least recorded influential factors in low-income households (n=2), whereas the middle-income range recorded 5, and the high-income homeowners were 4.

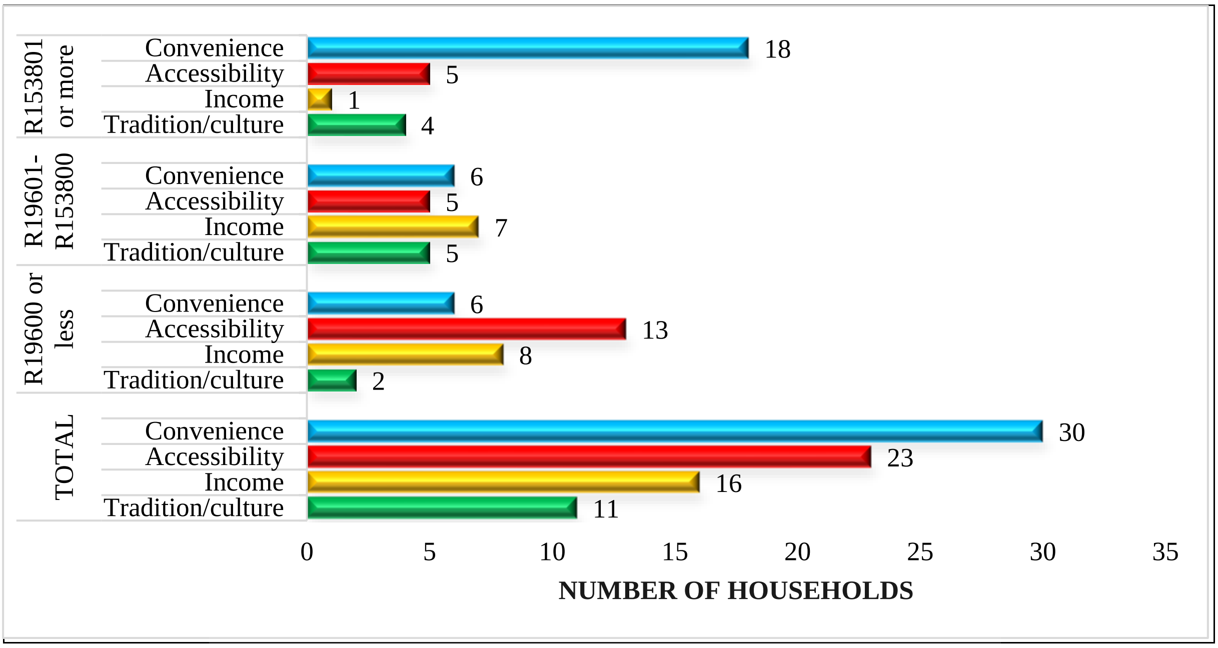

Figure 4.32: Factors influencing space heating fuel choice based on the total annual household income

Figure 4-33 details the cost of all energy sources used to meet households' energy needs, as per their income range. Expectedly so, the high-income range has the highest number of households (n=17) that spend more than R301 per month on all fuels, and the opposite is true for low-income households (n=6). Only 3 households in the high-income range spend less than R200 on fuel, of which the middle-income range is represented by 6 households and the low-income range by 10. The low-income range is more represented by households (n=13) that spent between R201 and R300 monthly. In non-electrified households, candles are commonly the only paid-for fuels, purchased at an average price of R25 per pack of 6 (2019 price).

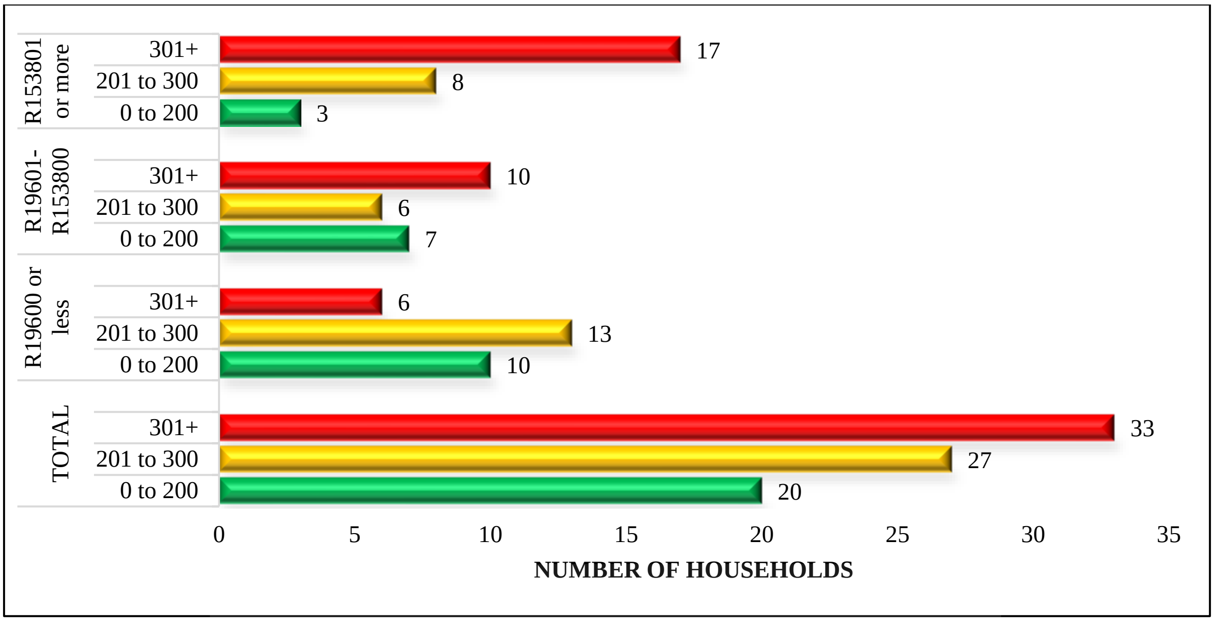

Figure 4.33: Monthly cost of fuel per household

Figure 4-34 presents the homeowners' perception of electricity price according to their income range. Overall results indicate that 58 of the 80 (≈73%) households find the price of electricity to be too high. The highest two records were those in low-income (n=23) and high-income (n=21) households reporting electricity as too expensive. Only 2 households reported that the cost of electricity as affordable/fair, these are in the high-income range. A nearly equal number of high-income earners chose either expensive (n=12) or too expensive (n=14).

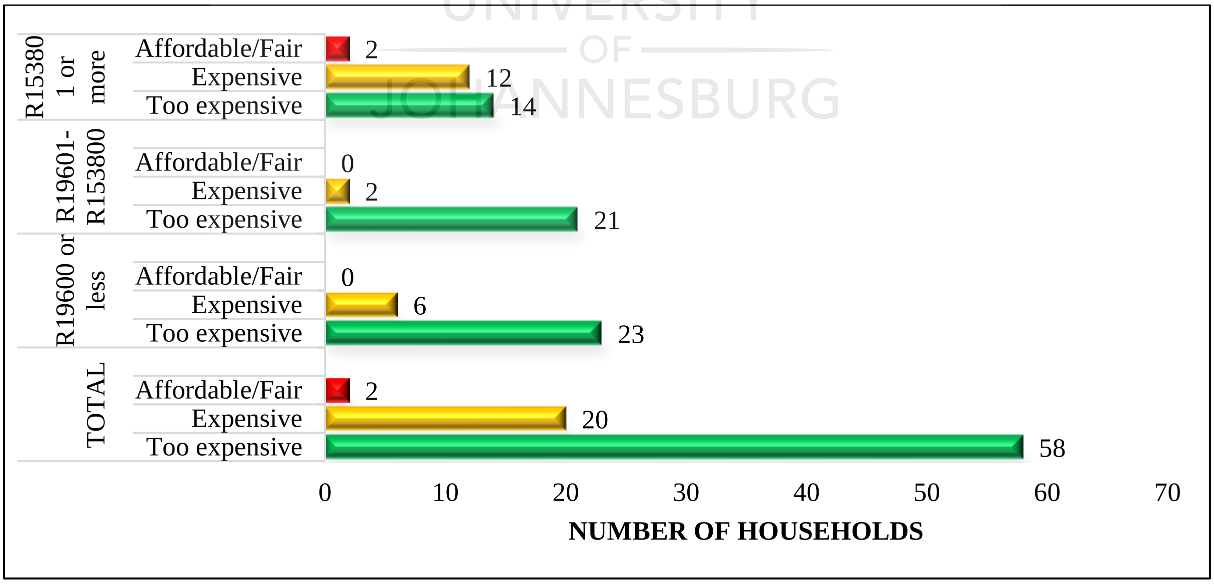

Figure 4.34: Homeowner's perception of electricity price

4.4. Summary of results

The frequencies presented for household demographics, fuels used and factors influencing the choice thereof give an indication of the social, economic and energy state in the area. The key results from this chapter are as follows:

- Electricity is used by less than 40% of the total sampled households for cooking.
- Contrary to literature, gender has no effect on the fuels selected in households.
- Homeowners younger than 40 years are less tradition/culture-oriented, thus their fuel choice was less influenced by taste and/or tradition/culture, and more by convenience, income, and accessibility. A positive significant correlation between age of homeowner and the use of firewood was established.
- The use of firewood in low-income households, older homeowners, those of lower education level and bigger households was more dominant (more than 40%).

5. DISCUSSION

5.1. Introduction

Chapter 5 discusses the results that were presented in chapter 4 (related Objective 1). Firstly, section 5.2 covers the trends for fuels used for cooking and space heating depending on different household demographics. Further, the section provides an analysis of inferential statistical analysis conducted between household demographics, the use of certain fuels to meet energy needs, and any correlation that might have been established. Section 5.3 discusses the implications of currently used fuels, that is the social, health, financial, and environmental impacts (Objective 2). In section 5.4, the solar PV as an alternative is explored, comparing the benefits of the technology against currently used fuels (Objective 3). The potential for adopting the solar PV technology is discussed. The chapter is concluded with section 5.5.

5.2. Household demographics, fuels choice and factors influencing fuel choice.

5.2.1. Fuel choice for cooking, lighting, refrigeration, entertainment, space- and water-heating

The first part of objective 1 was to determine the nature of energy needs and types of energy sources currently used to meet the basic rural household needs. In line with this, the study has found that wood and electricity were the most used fuels to meet various energy needs. The exact proportions of the fuels are detailed in this sub-section. The high proportion of firewood used for cooking (≈59%) in Atok is in line with the results from other researchers, where some even recorded values as high as 90% (Danlami & Applanaidu, 2018; Semenya & Machete, 2019; WHO, 2019). It was expected that 100% of electrified households would report the use of electricity for lighting due to the low cost and least complications associated with purchasing and connecting lights as opposed to other electrical appliances. This expectation was met, and the data also showed that the non-electrified households relied on candles for lighting. Candles are readily available at an affordable cost from the local tuck shops in the villages as compared to other alternatives such as lantern or paraffin lights. The use of candles in the non-electrified is thus supported by the cost and accessibility as recorded by previous studies (Ateba & Prinsloo, 2018; Ratshomo & Nembahe, 2018).

Refrigeration is one of the households' needs that are easily powered by electricity, thus all non-electrified households did not go to the extreme of finding alternatives to power refrigerators, hence no records in such households for it. The non-electrified households' refrigeration needs are thus not met, except for those who got assisted by neighbours. One of the participants mentioned, "We ask to store our frozen products, mainly meat, in relatives' refrigerators". For those who could not ask relatives or friends to store their frozen consumables, they simply avoid purchasing such or purchase frozen consumables from the local tuck shops. The latter is a bit more costly than when purchased in bulks from bigger markets in town. With the nearest shopping centre being more than 20km from the study area, this means these households would incur transport costs. As outlined in sub-section 4.3.6 and discussed further in sub-section 5.2.2, disposable income to cover such costs is not something these households have.

Space heating is one of the needs that households have. It was revealed that only 43% of the households had electrical heating appliance, however, those were not the only users of electricity for space heating. Some 25% of the total households reported the use of both electricity and wood for space heating. Such households mainly used electrical stoves to heat their spaces on occasions when they cannot use wood. A similar trend as that for space heating in the fuel choice for water heating was observed, with slight difference in the actual frequencies. The frequencies for wood, electricity only, combination of electricity and wood were as follows for water heating 29, 33, 18 and 26, 34, 20 for space heating. Due to the similarities observed in the results for water- and space-heating, a decision was made to discuss only factors influencing space heating in the proceeding sub-section. Water heating using electricity was either done by electrical kettles or pots on electrical stoves or electrical buckets, and in only 2 households by geyser for bathing. The number of firewood users for space- and water-heating was recorded to be higher than 50% in other parts of the world, and as high as 90% in some villages of Limpopo (Uhunamure, 2017; Semenya & Machete, 2019; Bede-Ojumadu & Orisakwe, 2020).

Entertainment is met by electricity in households with such access (n=64) and by battery in the remaining 16. This is merely an accessibility issue. In the olden days, before electricity connection was established in the area, generators were used to power televisions in households which could afford (about 1 in 10 households). However, that is no longer the case in the non-electrified households; they simply do not use televisions and use batteries for radios. This is due to their inability to afford the purchasing the generators and fuel thereof. The effect of income on which fuel choice is selected has been noted in previous studies (Abebwa, 2007; Bouzarovski & Petrova, 2015; Ifegbesan, et al., 2016; Sankhyayan & Dasgupta, 2019)

Results indicated that 100% of all the electrified households have these electrical appliances: irons, kettles, lighting and televisions/radios. The most common electrical appliances reported after these were stoves in 48 households, heaters (n=34), fans (n=13), washing machines (n=12) and computers (n=12). Only 2 households had geysers. Though in general, electrical stoves are more costly than heaters and fans, their use in households is for everyday needs (cooking), hence their popularity. On the other hand, the use of heaters and fans is seasonal and because of their purpose not really being an absolute need, some households survive just well without them. For example, during hot summer periods some households the members would sleep out in the open until midnight or just after midnight when inside the house has cooled down. Whereas some would opt for sleeping with slightly moist sheets which cool the body down. Other options such as sleeping with the windows open, spreading out in the bedroom and moving from sharing a bed to sleeping on the floor were mentioned.

Interestingly, the exact opposite of these cooling options was true for winter periods. The most common mentioned ways for space heating or self-warming were going to bed early, keeping the windows closed for most of the day, sleeping in packs and wearing warm night clothes as well as more blankets. Two least practiced, due to safety reasons, warming methods were mentioned: firstly, an old way was to keep a small fire in the bedroom, and secondly, keeping a plastic bottle filled with warm water by the feet. “We sit around the fire long enough to ensure the whole body is warmed up and run as fast as possible to bed to keep the warmth”, said one of the participants.

Hand washing is still quite common in the area, mainly due to the cost of washing machines but also mentioned by less than 5 old women to be a preference. The popularity of computers/laptops is low, due to their costs and advancement of cell phones. More people are learning to use their cell phones for duties that were previously achieved through computers.

5.2.2. Factors influencing fuel choice

The second part of the first objective was to determine the factors impacting the choice of energy sources in Atok, as discussed in this section. Inferential statistics of factors influencing fuel choice for cooking and space heating according to household demographics are discussed in this section. The discussion includes any correlation between variables and statistical significance that exists.

5.2.1.1. Gender

The trend for cooking fuel choice was similar for both genders of homeowners, where the most used fuel was wood only and the least used was the combination of electricity and wood. Space heating fuel choice displayed a rather different trend where electricity was the leading fuel used regardless of the gender, followed by wood in female-headed households, whereas wood was the least used in male-headed households. Though literature suggests a correlation between gender and the fuel choice for cooking (Kohlin, et al., 2012; Puzzolo, et al., 2014; Hou, et al., 2017), no significant statistical correlation was found between these variables in the study area.

Statistical analyses were conducted to determine a correlation between gender of homeowners and other factors namely, convenience, accessibility, income, food taste and tradition/culture. The results revealed that female homeowners are more influenced by food taste (≈40% of female-headed households) on their choice of fuel for cooking, followed by convenience (≈25%). However, the male homeowners displayed an equal influence by both food taste and convenience, contributing some 40% each. For space heating, female-headed households based their choice of fuel more on its convenience (16 of 48) and accessibility (17 of 48). In the male-headed households, convenience was the leading factor (≈44% of the male-headed households), with all the other three factors contributing equally to the fuel choice for space heating. Despite the differences in trends for these factors, which suggest that the homeowners decide on fuel choice inversely because of their gender, as literature has also revealed (Howells & Alfstada, 2005; Semenya & Machete, 2019; Choudhuri & Desai, 2020), no significant distinctive association was established in Atok households.

5.2.1.2. Age

The effect of age on fuel choice for space heating and cooking is detailed in figures 13 and 14. More homeowners (≈70%) older than 50 prefer firewood for cooking, compared to the other two fuel options, and even more than the other two age ranges. The use of both electricity and wood for cooking is evenly distributed throughout the age ranges. A record of twice the middle- and oldest-age range was recorded for the use of electricity for cooking. Literature supports these findings, where the use of firewood is more prevalent for cooking in households with older homeowners (Mekomen & Kohlin, 2009; Mensah & Adu, 2015; Semenya & Machete, 2019). On the contrary, more homeowners younger than 40 use firewood more (≈66% of households in this age range) than the other two fuels, and even more than the other two age ranges (with less than 20% of the households per age range). Instead, more than 59% of the oldest homeowners use electricity for space heating.

Homeowners older than 40 years are more cultural and traditional than the younger homeowners, and because firewood is part of most black South African traditions, the preference to use firewood over electricity for older household owners is expected. Taste has been observed as a significant role-player when it comes to choosing a fuel for cooking, mostly in households headed by the older generation. More than 70% of the households owned by people older than 40 prefer cooking with firewood because of the difference in taste between food cooked with firewood and electric stove. Food such as samp, pap, tripe, cow heel, and most traditional food are amongst those considered to taste better when cooked with fire. Most of the traditional food is slow-cooked, so that would not only consume time but leave one with an electricity bill.

The taste and cooking process factor on fuel choice was stated by van der Kroon, *et al.*, (2013: pp. 507): "*Although migrants can afford LPG and indeed purchase LPG stoves, they rarely use these stoves because the adoption of this new fuel also requires changes in food preparation traditions.*

Guatemala's two staple foods, beans, and corn require many hours of cooking and gas is considered too expensive for long cooking processes".

Though most of the younger homeowners (<40 years old) do not have electricity and thus use firewood for cooking, they mentioned that the taste of food does not play a role in their choice of cooking fuel. The younger homeowners and household members highlighted the ‘poverty’ stigma that is associated with using firewood and how they would appreciate having access to and being able to switch entirely to electricity. Furthermore, it was established that the older generation has firewood embedded in their lifestyle as supported by literature (Mensah & Adu, 2015) and most only got access to electricity in their late years; from 2005. A complete transition away from firewood is seen as abandoning tradition to the older homeowners.

The results on space heating fuel choice based on the age of the homeowner are rather unexpected, as literature has revealed that younger household owners prefer modern fuels (Mensah & Adu, 2015; Uhunamure, 2017; Hou & Liao, 2019). Figure 4-15 shows the external factors that influence the fuel choice for space heating, and there is a significant correlation between the age of the household owner and each of the factors. Most of the younger household owners (<40 years old) built their homes after electrification of the villages had already happened; thus, they do not have access to electricity, hence the use of firewood for space heating. The households' income is not sufficient for the residents to electrify their households. Very few of these households can afford space heating appliances. The affordable, accessible, and convenient fuel for households with younger owners then becomes firewood. Some household owners older than 40 years have limited mobility due to old age or chronic diseases such as arthritis and require space heating for longer hours. Therefore, older homeowners preferred electricity over wood for space heating, because the electrical space heating appliances can be used indoors, throughout the night and be carried around. The 12% of older homeowners that use firewood for space heating are doing so due to traditional/cultural reasons.

A further correlation between age and fuel choice was revealed when the participants were asked this question "If electricity was free, would you rely on it completely for all your energy needs?" and 51% of the people said no. Of the people that said no, 88% were older than 40 years. The main reasons for the answer 'no" were the food taste and tradition/culture, which is in line with findings by other researchers (Mekomen & Kohlin, 2009; Mensah & Adu, 2015; Hou & Liao, 2019; Semenya & Machete, 2019).

5.2.1.3. Marital status

Owing to the combined income of a married couple's household (if both spouses gain income) the supply of energy for cooking services becomes more affordable than for single household heads.

However, it can be argued that the reverse is true if only one member of the married couple receives income, i.e., the size of the household would raise the energy demand, but only one source of income. One of the married female participants who was recently retrenched from the local mine highlighted this: “Finances are limited, however, the number of mouths to feed and needs to be met remain the same”. Married couples tend to have higher monthly costs than a single-headed family as noted in other studies (Mensah & Adu, 2015; Karakara & Dasmani, 2019). A similar pattern for both marital status categories was observed for cooking fuels. Wood was the leading used fuel by more than 58%, followed by the combination of electricity and wood, and lastly electricity only. The main difference noted was the use of both electricity and wood, which was represented by only 1 household in category1 as opposed to 8 in category2, but it was still the least used fuel for both categories. Space heating was achieved prevalently through electricity, regardless of the household head’s marital status.

Convenience proves to be a more contributing factor to the fuel used for space heating in partnered households. For single homeowners, accessibility is the most contributing factor to their preferred fuel for space heating (more than 35%), as opposed to only 17% of the households choosing a cooking fuel based on the accessibility. The association of homeowner’s marital status and their fuel preference for either cooking or space heating could not be established for either Mogabane or Maropeng village, though literature has found a significant statistical correlation between fuel choice and homeowner’s marital status (Mensah & Adu, 2015; Karakara & Dasmani, 2019).

5.2.1.4. Household size

As mentioned earlier in the marital status sub-section, an increase in members of the household without increasing the income can result in more use of traditional fuels. All three household size categories displayed a similar trend for cooking using wood predominantly, followed by electricity only, then electricity and wood combination. However, the percentage of using wood in bigger households (category3) was the highest at just above 88%, followed by category1 households at just above 68%. It is more convenient to cook bigger pots with firewood than it is with electric stoves. The electric stove can only take certain sized pots and thus limiting the number of people that can feed from those pots. The use of firewood for cooking during events is also quite common, because a larger number of people are catered for.

The highest proportions of electricity users for space heating were recorded in categories 2 and 3 (around 45%). These space heating figures are slightly contrasted to the literature (Suliman, 2013; Ebe, 2014; Rahut, Behera & Ali, 2016; Danlami & Applanaidu, 2018), as more of the households with fewer members use firewood over electricity as opposed to bigger households’ size. The probability of using modern fuels is expected to decline with increasing household members, as suggested by literature (Mensah & Adu, 2015; Uhunamure, 2017).

An interesting point mentioned under household size were the dynamics of water heating. The bigger the family, the more convenient it is to heat water with firewood. It would be difficult, time-consuming, and costly to warm bathing water using the electric kettle for a household of ten individuals. A 1.7l kettle must be boiled at least three times to get enough bathing water for one person, which means boiling the kettle thirty times daily in a household of ten members just for bathing water.

Percentage of households that are influenced by convenience on making fuel choice for cooking per household size increases with the number of members, from just above 31% in category1, to some 40% in category2, to more than 61% in category3. This is an indication of how convenience matters more for bigger households than smaller ones, as mentioned earlier on the issue of using firewood to accommodate bigger pots (feed more family members) that do not fit on electric stoves.

5.2.1.5. Level of education

Knowledge is power, and thus the level of education of the decision maker is key in households. The fuels used are distinctive for the two education categories. Homeowners that never matriculated use more wood than those who have matric or obtained higher education. In the matric or above category, 47% of the households use electricity only for cooking against only 17% of the non-matriculated category. A similar ratio is true for space heating where only 28% of the homeowners without matric indicated the use of electricity as opposed to above 61% of those who matriculated.

Higher education level is associated with better-paying jobs and the use of electricity more than firewood. Only 42% of the household's heads have matriculated, this may be due to the proportion of older homeowners that grew up in times where education was not as prioritised as currently. The trends in figures 4-24 and 4-25 indicates the use of firewood by more than 74% of the households headed by individuals without matric, compared to just 39% of those who matriculated. Though no statistically significant correlation was found, there are more households using electricity over firewood for higher educated heads. This conforms with findings by Danlami and Applanaidu (2018), that the more educated the head of the household, the more likely they know of negative impacts of using biomass fuels and hence the use of much cleaner fuels such as electricity. Convenience was reported the most important factor for choosing fuel for cooking and space heating in households with higher education level. In households of lower education, convenience was the second last influential factors. It appears that the factors influencing fuel choice and the homeowner's level of education are co-dependent. The knowledge on FBE was extremely high in all households regardless of the homeowners’ education level (≈85% for matriculated homeowners and ≈93% for those with only up to high school).

5.2.1.6. Income

The use of firewood drops with increasing household annual income, from about 79% in category1, to 65%, and finally to about 32% in category3. This is explained by the fact that firewood is free and thus the households that earn the lowest can easily access the fuel, as opposed to electricity which must be purchased. Households in Atok villages spend between R200 ($13.2) and R500 ($33.1) on average monthly on electricity, which is more than 10% of the household income for approximately 40% of the households. This explains the high dependence on firewood even in electrified rural households of Mogabane and Maropeng villages.

Amongst the factors influencing the use of firewood in households, income is the most influential factor for heating purposes. More than 50% of the households that use firewood for space/water heating are doing so because of their level of income. These households cannot afford heating appliances and the electricity to use the appliances. Most households would be using electrical heaters and geysers if electricity was free or affordable, so they opt for firewood for heating water and space heating because of the low household income. 70% of households with access to electricity household spend between R201 ($13.3) and R400 ($26.5) on electricity per month; a mere 3% spend above R401 ($26.54) per month. Firewood is accessed for free from the nearby bushes for daily use and bought for R500 per a load of 250kg firewood. The extensive use of firewood because of low-income households has been observed in other studies (Mensah & Adu, 2015; Hou & Tang, 2017; Danlami & Applanaidu, 2018).

Access to electricity is also linked to household income level, relating income indirectly with the use of firewood in households with no access to electricity. The relation is that households without access to electricity are low-income households, and it is not by choice, but rather by circumstances that they cannot electrify their households. The major factor is the cost of privately electrifying the household. Only 2.5% of the households mentioned that electricity is affordable, while about 73% said it is too expensive, and the other 25% said it is costly. It was interesting to hear more than 50% of the participants answer "no" when they were asked if they would switch to electricity completely if electricity were free. This figure tells us that though income influences the fuel choice decision making process, it should not be considered as the only or main factor, thus neglecting other influential factors.

5.3. Implications associated with currently used fuels

Objective 2 was to uncover social, financial, and environmental implications associated with the fuels currently used in these households. These implications are based discussed in detail in this section. The 16 households that are still without electricity in the villages of Atok continue to suffer the negative impact of using firewood and candles. 100% of the households, through a prompted questionnaire, highlighted that they are concerned about their safety and economic productivity, which are compromised by the use of hazardous and time-consuming fuels. Refrigeration, space cooling and entertainment are amongst the top energy needs that cannot be met in these households due to no access to electricity. The households with access to electricity (64) are not exempted from the above-mentioned challenges, as some also depend on some sort of traditional fuels to a certain extent. In addition to those, electrified households face challenges such as power cuts and not affording electricity and/or electrical appliances.

5.3.1. Social Implications

The wood collection activity is time-consuming and physically straining. Women and children are responsible for the collection of wood in the households. They spend a total of 1 to 2 hours daily collecting firewood, this is time that could be used otherwise for economic contribution or educational purposes and exposes them to negative impacts provided by literature (Howells & Alfstada, 2005; WHO, 2015; Weber & Sotelo, 2017; Arku and Brauer, 2018). Power cut-offs have negatively impacted the lives of Atok residents. In the first few months of 2020, load shedding occurred throughout the country, affecting everyone who had no backup. House chores schedules had to be changed to adjust to the power outage schedules. In some cases, the power outage schedules were not adhered to by Eskom, which resulted in even more disruption of running households. Network coverage would also be cut-off for the duration of a power outage, which affected mostly those who were working or studying from home. Literature supports these challenges, highlighting the high electricity tariffs for unreliable power supply faced by African households (Mensah & Adu, 2015; Ouedraogo, 2017). It is demeaning for homeowners that have to ask for their consumables to be stored in other people’s refrigerators and sometimes inconvenient for the storing household. The same can be said for household members that have to ask other for cell phone charging or watching television.

5.3.2. Financial Implications

More than 40% of the households in Atok Village spend 10 to 15% of their total household income on fuel expenditure monthly. This is a phenomenon known as energy poverty where households rely on more than one fuel for various energy needs or spend more than 10% of their total household income on fuel. The use of firewood has been associated with low income in more than 50% of the households (Figure 4-34). The finances spent on bills monthly could be redirected to other basic needs such as food.

5.3.3. Environmental Implications

The environmental implications associated with the use of firewood would include deforestation, forest degradation, forest regeneration, and other tree cover problems. There is no forest rehabilitation plan put in place in the areas where firewood is collected, and this exposes the area to more erosion. Relying greatly on fossil fuels leads to increased carbon dioxide emissions, global warming, and irregular weather patterns as indicated in literature (Eskom, 2019; Irfan, 2019; Eskom, 2020).

To address the environmental effects of using firewood, the government should consider having awareness campaigns to educate the people on the impacts of continued reliance on scarce resources, which they are depleting at a rapid pace. A package of energy services such as paraffin and renewable energy alternatives such as hybrid mini-grid systems, gel fuel, solar cookers, and solar water heaters can be employed to cater to the households. The mentioned modern energy systems will provide cleaner, healthier, and better energy services, as well as help in saving the remaining woodlands.

5.3.4. Health Implications

Women and children that chop down trees and transport the wood have somehow suffered personal injuries or pains from the exercise. Due to limited resources, this study could not investigate and prove any respiratory or internal illnesses that were potentially caused by the use of firewood. For households that have to use their neighbours or relatives' refrigerators, their health is at risk as the condition of storage is not always guaranteed to be the most suitable for their consumables. Such households are also at a higher risk of contracting Corona virus as they have to constantly visit the other household to fetch their consumables.

To curb the negative impacts by currently used fuels, alternative fuels should be explored. Using improved cooking stoves and cleaner fuels can improve livelihoods, reduce deforestation, improve human health, and mitigate climate change (WHO, 2015). Products such as Zama Zama by Rocket Works can be considered to provide clean firewood use without taking away the tradition and excellent food taste from the people. Women must be involved in the designing of the improved stoves for a successful implementation of cooking stove programs and new energy policies. The involvement of women in daily house chores such as cooking makes them the suitable participants in households' energy policy formulation and improvement. Due to the daily solar radiation of the villages which ranges between $14MJ/m^2$ to $22MJ/m^2$, (Schulze & Maharaj, 2004) solar PV technology should be explored, as discussed in the proceeding section. This radiation is sufficient to run households' basic energy needs entirely on solar systems.

5.4. Solar PV technology as an alternative

This section addresses the last objective which was to Assess and compare the social, financial, and environmental impact of applying solar PV technology, in relation to currently used traditional energy fuels in these households. Selecting an alternative appropriate energy technology depends on political, social, environmental political, cultural, economic, and technical dynamics (Dorji, 2012). The efficacy of solar PV as an alternative reliable and pollution-free energy technology is explored. The daily mean solar radiation in Limpopo ranges from 14MJ/m^2/day in winter to just below 23 MJ/m^2/day in summer, as seen in Figure 5-1 (Shulze & Maharaj, 2010; Matasane, 2014).

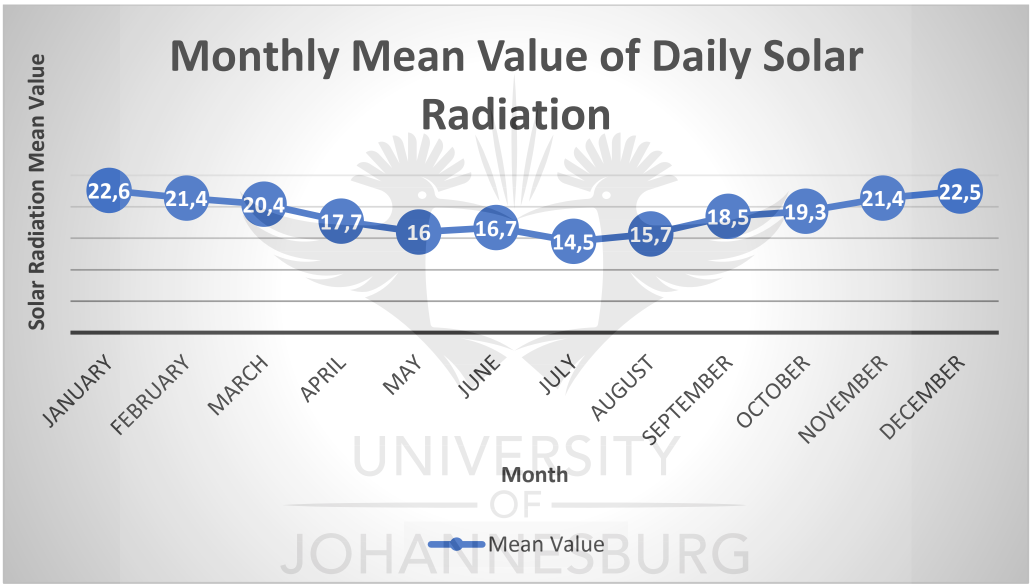

Figure 5.1: Monthly means of daily solar radiation in Limpopo (Shulze & Maharaj, 2010; Matasane, 2014)

The total load of 20.76kWh as indicated in Table 5-1 was used to determine the adequate solar system and battery storage capacity required for a household of five members and five rooms. Due to the high starting current of appliances with a heating element such as electric geysers and electric stoves, solar systems suppliers Artsolar (2020), and SustainableSolar (2020), are against the use of such appliances. The suppliers recommend the use of gas stoves and solar geysers to avoid the tripping or blowing up of the inverter.

Table 5.1: Households electrical appliances

Appliance	Power rating (W)	Number in use	Hours used	Total Load (Wh)
Kettle	1500	1	0.5	750
Iron	1000	1	0.1	100
4-plate stove	2000	1	2	4000
Light bulb	60	6	8	2880
Television	60	1	5	300
Radio	12	1	5	60
Fridge	300	1	24	7200
Charging ports	5	5	2	50
Geyser	3000	1	2	6000
Heater	70	1	6	420
Total	**8007**	**19**	**54.6**	**21760**

A grid-solar PV hybrid system connection like that in Figure 5-2 is considered for this study. In other states, the electricity flow between the grid and inverter is bi-directional to allow excess power generated by the households to be fed back into the grid. However, that policy is not available in South Africa, and thus the unidirectional flow. This outlined hybrid system allows for the battery to be charged by both the grid and solar PV, though the grid only charges the battery when solar PV is not receiving enough sunlight such as on rainy days or at night.

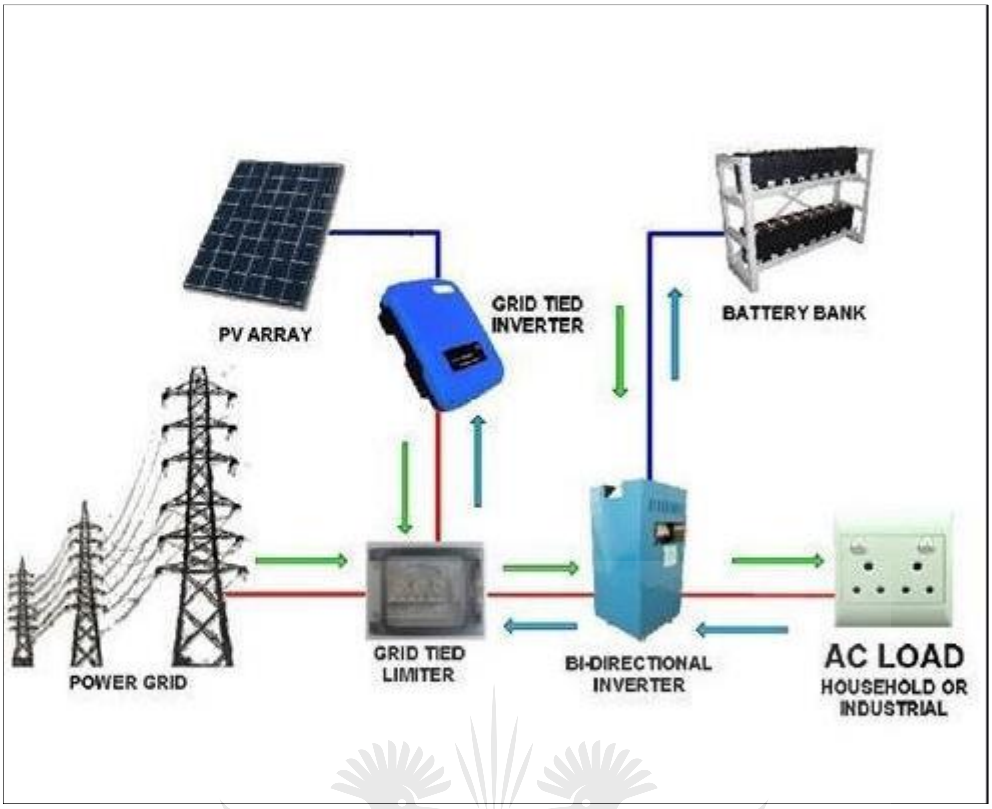

Figure 5.2: Hybrid grid-solar PV household connection (ArtSolar, 2020)

The use of the above-mentioned solar PV system does not cater for electric geyser and electric stove. The solar system can be used in conjunction with electric stove and electric geyser, which reduces the daily grid-electricity load by 10kWh. Alternatively, the solar system with backup batteries can be used with a gas stove and a solar geyser, which allows for no dependency on the grid. Two solar systems were considered in this study: 1. a solar PV system with 20 years life cycle, producing an average of 10kW solar PV system with 45kWh backup, and 2. a 5kW solar PV system with 14kW backup. The specifications and pricing of the solar PV system as obtained from the supplier are detailed in tables 5-2 and 5-3.

Table 5-3 indicates that more than 50% of the cost of the system is carried by the batteries. Due to the lifecycle of 5 years, the battery system would have to be replaced 4 times in the 20 years of the solar PV system, thus increasing the total cost to R130 5698. This total cost for the solar PV is massively high considering the income range and monthly cost of fuel of the Atok households. Backup power is required mostly at night, and thus households can decide to use only the necessary appliances at night i.e., refrigerator and lights. This will minimize their reliance on backup power and thus reduce the capacity and cost of required batteries. The system detailed in Table 5-2 was disregarded due to the excess kWh it produces and the high cost associated.

Table 5.2: Cost of 10kW solar PV system with 45kWh battery storage and installation cost (Artsolar, 2020)

10 KW System with 45 KWh Backup			
Item	**Cost (excl vat)**	**Quantity**	**Price (excl vat)**
Kodak Solar Off Grid Inverter MKS11 5KW 48V	R12 500.00	2	R25 000.00
Solar Panals 425 wp	R2 082.50	22	R45 815.00
3.5 KWh 48V Lithium Batery	R20 600.00	12	R247 200.00
MC4 Connector Twin Pack	R200.00	2	R400.00
Solar Cable 4mm2	R11.50	250	R2 875.00
Combiner Box 2 in 2 out	R5 000.00	1	R5 000.00
Essential DB	R4 000.00	1	R4 000.00
Earth Cable 16mm2	R40.00	50	R2 000.00
Battery Cabinet US3000B X 4	R4 700.00	3	R14 100.00
Cable Pack	R300.00	3	R900.00
Tile Mounting Structure	R750.00	22	R16 500.00
Installation Cost	R30 000.00	1	R30 000.00
Total (excl vat)			R393 790.00
Vat (%)			15.00%
Total (incl vat)			R452 858.50

The system detailed in Table 5-4 was considered for LCOE calculations done to determine the most financially viable fuel for Atok households as illustrated in equation 5.1. LCOE caters for the comparison of different energy technologies with different project size, life spans, different capacities, capital cost, risk, and return on investment (U.S. DOE, 2019; Irfan, 2019). Solar PV installation cost is included in the initial capital cost.

Equation 5.1: LCOE equation

$$LCOE = \left(\sum_{c=1}^{n} \frac{I_c + M_c + F_c}{(1+d)^c}\right) / \left(\sum_{c=1}^{n} \frac{E_c}{(1+d)^c}\right)$$

Firewood is collected in the nearby bush; thus, no cost is associated with firewood, resulting in LCOE of 0. The cost of electricity to power appliances mentioned in Table 5-1, excluding the stove and the geyser, is calculated using equation 5-2 below. The Eskom tariff per kWh varies throughout the month, for this study the price of R1.80/kWh is used.

Equation 5.2: Monthly electricity cost formula

Monthly Electricity cost is calculated as follows:

= (the cost in Rands of 1kWh) * (the total household load kWh/day) *(days in a month)

= (1.8) *(11.76) *30

= R635.04

It would cost a household with all the appliances mentioned in Table 5-1, except geyser and stove, R635.04 per month. This is more than six times the current amount that is being spent on electricity by 20% of the households. Just above 70% of the households spend around half of this monthly electricity cost on fuel. An average household in Atok spends R300 per month on electricity, yet many of their energy needs are still not met. The monthly expenditure of R300 on electricity means the household's daily total load is the only 5.5kWh. Over 20 years, assuming an annual increase of 5% on the tariff and keeping the daily total load constant, each of these households would have spent approximately R90 000 on electricity.

Table 5.3: The cost of a 5kW solar PV system with 14kWh backup (Artsolar, 2020)

5 KW System with 14 KWh Backup			
Item	Cost (excl vat)	Quantity	Price (excl vat)
Kodak Solar Off Grid Inverter MKS11 5KW 48V	R12 500.00	1	R12 500.00
Solar Panals 425 wp	R2 082.50	10	R20 825.00
3.5 KWh 48V Lithium Batery	R20 600.00	4	R82 400.00
MC4 Connector Twin Pack	R200.00	1	R200.00
Solar Cable 4mm2	R11.50	100	R1 150.00
Combiner Box 2 in 1 out	R4 000.00	1	R4 000.00
Essential DB	R4 000.00	1	R4 000.00
Earth Cable 16mm2	R40.00	50	R2 000.00
Battery Cabinet US3000B X 4	R4 700.00	1	R4 700.00
Cable Pack	R300.00	1	R300.00
Tile Mounting Structure	R750.00	10	R7 500.00
Installation Cost	R15 000.00	1	R15 000.00
Total (excl vat)			R154 575.00
Vat (%)			15.00%
Total (incl vat)			R177 761.25

The battery lifecycle is 5 years, thus driving up the battery cost by four times the amount provided in the quotation (Table 5-3) giving a total cost of R46 2041.25. The values provided in Table 5-4 were used for LCOE calculations for both solar PV and grid electricity. LCOE for solar PV was calculated to be R4.69/kWh, which is higher than R3.07/kWh for grid electricity. It is on this basis, that the conclusion that solar PV is not economically feasible for the rural households of Atok is reached.

Table 5.4: LCOE value of grid electricity against solar PV technology over 20 years

Technology	**Grid**	**Solar PV**
I_c (ZAR)	0	46 2041.3
M_c (ZAR	0	0
F_c (ZAR)	26 4196	0
E_c (ZAR)	4 233.6	5400
d (%)	0.01	0.01
c (year)	1 to 20	
LCOE	**3.07033**	**4.69456571**

The rural households do not earn enough to afford the high initial cost of solar PV system. However, had it been proven that the system is financially feasible, i.e., cost over 20 years is less than the cost of grid-electricity, a donor-driven solar project like that in Nyimba (Zambia) would be suggested. The Zambian government carried out a solar PV rural electrification pilot project where Energy Services Company (ESCO) installed solar PV systems and charges customers a service fee. The customers enjoy solar lighting without paying the high capital cost and not having to worry about the maintenance of the system (Jenkins & Baurzhan, 2014). Similarly, a suggestion to roll out a project to install solar PV technology paid for by the South African government and the rural households of Atok pay a monthly fee over 20 years would be made. Providing free or subsidised solar panels/systems for households is a way to help people's reliance on electricity. Solar water heaters are a great example of an implementation needed for the people. The government can consider installing free solar systems in households that allow households to feedback to the grid such that they spend less on electricity.

Solar PV technology offers industry regrouping, job creation, new skills creation, and can help with Demand Side Management. Carbon dioxide emissions per household would be reduced by 8 279.76kg/kWh over 20 years when solar PV is used instead of grid electricity. Amid the environmental and social benefits of solar PV technology for the rural households of Atok, solar PV technology is neither economically nor financially feasible for these rural households. Considerations of solar PV technology for the households of Atok requires policies that allow for rebates, feeding back to the grid, subsidies and discounted rates from the government, suppliers as well as Eskom.

5.5. Summary of research highlights

There is a high (≈59%) proportion of firewood used for cooking in Atok. More homeowners (≈70%) older than 50 prefer firewood for cooking, compared to the other two fuel options, and even more than the other two age ranges. This is due the attachment that the older homeowners have to tradition/culture and food taste associated with using firewood. However, older homeowners were more influenced by convenience and accessibility in their choice of fuel for space heating, thus choosing electricity more than wood. Approximately 51% of the respondents said they would still not move to electricity even if it was completely free, of this proportion more than 88% were homeowners older than 40 years old.

A similar pattern for both marital status categories was observed for cooking fuels. Space heating was achieved prevalently through electricity, regardless of the household head’s marital status. Convenience proves to be a more contributing factor to the fuel used for space heating in partnered households. For single homeowners, accessibility is the most contributing factor to their preferred fuel for space heating (more than 35%), as opposed to only 17% of the households choosing a cooking fuel based on the accessibility.

There was no distinguished trend for the fuel choice for both cooking and space heating established in terms of the household size. However, the percentage of using wood in bigger households (category3) was the highest at just above 88%, as it is more convenient to cook bigger pots with firewood than it is with electric stoves. The electric stove can only take certain sized pots and thus limiting the number of people that can feed from those pots. For the same reasons, the use of firewood for cooking during events is also quite common, because a larger number of people are catered for.

An interesting association between income and other variables was observed. Atok residents are mostly patriarchal thus the promotion of education for females is not as much as for males. As a result, because there more female headed households, that means there are more homeowners within the lower education level. Additionally, the higher the education level one obtains, the more income they are likely to get. With that being said, women are put at a disadvantage to earn a reasonable income. Moreover, until recently women were encouraged to stay home instead of finding employment, which meant more homeowners without any income. Unfortunately, the use of firewood is directly linked with low or no household income globally. Thus, more females are more prone to using firewood, even though there was no statistical correlation in the study area between gender and selected fuel. The results showed that 60% of the female homeowners used firewood for cooking as opposed to about 56% in the male-headed households.

The Chi-square tests for independence in this study revealed these key results:

i. No significant correlation was established between gender and fuel choice or any of the external determinants.
ii. A positive correlation was documented between the age of the homeowner and the use of firewood, as well as the extent to which older homeowners were influenced by food taste on their cooking fuel selection.
iii. Marital status showed no statistical relationship with either fuel choice or factors influencing the fuel choice. Thus, the proportion of married/partnered homeowners that use certain fuels or are influenced by certain factors to select a fuel was not significantly different from that of single-headed households.
iv. There was an error in the statistical analyses determining a relationship between household size and fuel choice, (i.e., the numbers of cells with a count of 5 or more were less than 80% at ≈67%).
v. A significantly positive correlation between the homeowner's level of education and the use of electricity. The proportion of wood users that had only up to high school was significantly higher than that of homeowners with higher education level. The homeowner's probability to be influenced by convenience on their fuel selection was more in households with higher education level than those with just up to high school.
vi. There was a significant association between the total annual household income and fuel choice. The percentage of high-income households using electricity was found to be significantly different from that of low-income earners. The latter were more influenced by their finances when selecting fuels due to the limited exposable income.

More than 40% of the households in Atok Village spend 10 to 15% of their total household income on fuel expenditure monthly. The use of firewood has been associated with low income in more than 50% of the households. The finances spent on bills monthly could be redirected to other basic needs such as food and clothes.

Women and children as the primary wood collectors suffer pains from the chopping down of trees and carriage of the wood home. Time and energy are lost, resources that could be redirected for economic benefit or improving performance at school (for the children). Therefore, alternative energy technologies have to be considered that put the household members' safety and health first, as well as to retain their dignity. As, such Solar PV feasibility was explored and it was discovered that even though there is sufficient radiation in the area, the technology would cost more over the next 20 years (at LCOE of R4.69/kWh ($0.31/kWh), which is higher than R3.07/kWh ($0.2/kWh) for grid electricity). Unless some drastic economic changes happen for the rural households of Atok, it will be long before they can afford solar PV technology.

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Females head more households than males in the studied villages, though a relationship between the gender of the homeowner and fuel preference could not be established. Marital status of the homeowner was also found to be irrelevant to fuel selection. Influential factors to the fuels used in the rural households of Atok are age, household size, education, income, and convenience. Homeowners older than 40 years old were found to prefer the use of firewood for cooking due to the distinct taste that firewood offers, more especially to traditional foods. Homeowners over 40 years of age are more cultural and traditional than younger homeowners, and since firewood is part of most of South African black culture, priority is expected to be given to the use of firewood over electricity by older homeowners. Meanwhile, homeowners younger than 40 years old use of firewood is more based on income and not having access to electricity. Bigger households (more than 4 members) rely on firewood for its convenience to cater for their household needs. Lower education level is associated with the use of firewood more than electricity, because of lack of awareness on firewood health impacts as well as lower income associated with being less educated.

Income, convenience, food taste, tradition/culture and access to electricity have proven to influence the use of firewood in the two villages. A great correlation between income and other factors such as household size and education level was established, i.e., the factors are interlinked when it comes to household’s fuel preference. For instance, lower education level mainly results in no employment or less paying jobs, thus low-income household and ultimately households resorting to firewood as it is free. Similarly, bigger households require more income to meet their energy needs, thus higher electricity bill, as a result, households resort to firewood. As cooking with firewood also offers convenience to bigger households in terms of time taken to cook, bigger households prefer firewood.

It was revealed that the participants were barely aware of most of the implications associated with their currently used fuels, apart from the obvious grid electricity power cuts, firewood collection time and strain associated with it. Though households mentioned their knowledge and understanding solar PV technology, its potential as an alternative for the household is almost impossible due to the high costs associated with it. Although the cost of the solar PV system in South Africa has decreased over time, it remains much higher than the world average, and the situation cannot be expected to improve soon unless political, financial, and economic conditions stabilize in the region. Many rural poor, as the targeted population of off-grid solar PV systems, cannot afford to purchase even the smallest device at the most advantageous rates. Given the very low-income level and economic activity in the villages of study, solar PV technology is out of reach for more than 80% of the households. However, the technology can not entirely be disregarded as an alternative, other options such as micro-grid or hybrid systems funded by the government can be investigated.

6.2. Summary of recommendations

i. Improved information sharing or awareness campaigns regarding the effects (i.e. environmental, health, social etc.) of utilising firewood.
ii. Promote the use of efficient cook-stoves – for instance, use those with lower air pollution rates (e.g. Zama-Zama stoves, or Basa njengo Magogo cook-stoves).
iii. Encourage households to participate or get involved in agricultural activities so as to *inter alia* improve socio-economic livelihood.
iv. Create conditions for the use of solar lights instead of candles among non-electrified households. Moreover, introduce tariff rebates for households using solar water geysers.

6.3. Suggested future works

Future research could focus on the impacts of firewood on deforestation levels in Atok or their effects on regional climate change in the area. Other studies could be on the perceptions of the villagers towards the contribution of biofuels to their climate, health, and economy. More awareness study could be on how aware the villagers are of the health impacts the use of firewood has and find out if they somehow blame it for some of the illnesses in the area. Firewood is currently accessed from the bushes not far from the households; however, new houses are being built and occupying the areas where firewood is collected from. This will result in fewer bushes or woodlands around the households and thus making firewood a scarce fuel and increasing firewood collection time. Research can be done on fuel types that will be suitable for the villagers considering that income, access to electricity, and food taste are the major role players in choice of fuel type. The specific research can focus on providing cleaner energy solutions for the households and catering to the energy demands of the villagers. Micro-grids allow all connected users to use the same generated energy, thus improving equity between users' consumptions. The use of solar PV plants, micro-grids and/or hybrid systems can be looked into, due to the benefit of cost reduction by economic scale as well as flexible consumption.

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Appendix I: Questionnaire

Note: Some questions were recoded for SPSS analyses

Household Demographics

1. What is your gender?

- Female
- Male
- Other (specify)

2. How old is the household owner?

- 18-20
- 21-29
- 30-39
- 40-49
- 50-59
- 60 or older

3. What is the marital status of the household owner?

- Single
- Married
- Partnered
- Divorced
- Widowed
- Separated

4. What is your household size?

- 1-3
- 4-6
- 7-10
- 10+

5. What is the highest level of school you have completed or the highest degree you have received?

- None
- Primary
- High school
- Matriculated
- College qualification
- Undergraduate Degree
- Post-graduate Degree

6. How many members of the family are employed?

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9

- 10
- 10+

7. Who is employed in the household?

- Parents
- Eldest sibling
- Other siblings
- Uncle/Aunt
- N/A
- Other (please specify)

8. What is the total household annual income?

- No income
- R4800 or less
- R4801-R9600
- R9601-R19600
- R19601-R38200
- R38201-R76400
- R76401-R153800
- R153801-R307600
- R307601-R614400
- R614401 +

9. How many pensioners are in the household?

- 0
- 1
- 2

- 3
- 4
- 5+

10. How many rooms are rented out?

- 0
- 1
- 2
- 3
- 4
- 5+

Fuel use

1. Which of the following fuels are used for the energy needs indicated (select all applicable)?

	Cooking	Lighting	Refrigeration	Space heating	Space cooling	Water heating	Entertainment
Wood	☐ Wood Coo king	☐ Wood Lig hting	☐ Wood Refrig eration	☐ Wood Sp ace heating	☐ Wood Sp ace cooling	☐ Wood W ater heating	☐ Wood Enterta inment
Paraff in	☐ Paraffin C ooking	☐ Paraffin Li ghting	☐ Paraffin Refri geration	☐ Paraffin Space heating	☐ Paraffin Space cooling	☐ Paraffin Water heating	☐ Paraffin Enter tainment
Electr icity	☐ Electricity	☐ Electricity	☐ Electricity Re	☐ Electricit y Space	☐ Electricit y Space	☐ Electricit y Water	☐ Electricity Ent

	Cooking	Lighting	Refrigeration	Space heating	Space cooling	Water heating	Entertainment
	Cooking	Lighting	frigeration	heating	cooling	heating	ertainment
Gas	☐ Gas Cooking	☐ Gas Lighting	☐ Gas Refrigeration	☐ Gas Space heating	☐ Gas Space cooling	☐ Gas Water heating	☐ Gas Entertainment
Candles	☐ Candles Cooking	☐ Candles Lighting	☐ Candles Refrigeration	☐ Candles Space heating	☐ Candles Space cooling	☐ Candles Water heating	☐ Candles Entertainment
Generators	☐ Generators Cooking	☐ Generators Lighting	☐ Generators Refrigeration	☐ Generators Space heating	☐ Generators Space cooling	☐ Generators Water heating	☐ Generators Entertainment

2. Which of the following affects your choice of fuel for the mentioned energy needs?

	Cooking	Lighting	Refrigeration	Space heating	Space cooling	Water heating	Entertainment
Taste	○ Taste Cooking	○ Taste Lighting	○ Taste Refrigeration	○ Taste Space heating	○ Taste Space cooling	○ Taste Water heating	○ Taste Entertainment
Tradition or Culture	○ Tradition or Culture Cooking	○ Tradition or Culture Lighting	○ Tradition or Culture Refrigeration	○ Tradition or Culture Space heating	○ Tradition or Culture Space cooling	○ Tradition or Culture Water heating	○ Tradition or Culture Entertainment
Income	○ Income Cooking	○ Income Lighting	○ Income Refrigeration	○ Income Space heating	○ Income Space cooling	○ Income Water heating	○ Income Entertainment

	Cooking	Lighting	Refrigeration	Space heating	Space cooling	Water heating	Entertainment
Accessibility	◯ Accessibility Cooking	◯ Accessibility Lighting	◯ Accessibility Refrigeration	◯ Accessibility Space heating	◯ Accessibility Space cooling	◯ Accessibility Water heating	◯ Accessibility Entertainment

3. How many hours are required daily to meet these energy needs?

	Cooking	Lighting	Refrigeration	Space heating	Space cooling	Water heating	Entertainment
0-2	☐ 0-2 Cooking	☐ 0-2 Lighting	☐ 0-2 Refrigeration	☐ 0-2 Space heating	☐ 0-2 Space cooling	☐ 0-2 Water heating	☐ 0-2 Entertainment
3-5	☐ 3-5 Cooking	☐ 3-5 Lighting	☐ 3-5 Refrigeration	☐ 3-5 Space heating	☐ 3-5 Space cooling	☐ 3-5 Water heating	☐ 3-5 Entertainment
6-9	☐ 6-9 Cooking	☐ 6-9 Lighting	☐ 6-9 Refrigeration	☐ 6-9 Space heating	☐ 6-9 Space cooling	☐ 6-9 Water heating	☐ 6-9 Entertainment
10+	☐ 10+ Cooking	☐ 10+ Lighting	☐ 10+ Refrigeration	☐ 10+ Space heating	☐ 10+ Space cooling	☐ 10+ Water heating	☐ 10+ Entertainment

4. Which of the following electrical appliances do you use in your household?

☐ Kettle

☐ Iron

☐ Television, radio and/or cell phone

☐ Washing Machine

- [ ] Dishwasher
- [ ] Geyser
- [ ] Computer/ laptop
- [ ] Fan
- [ ] Heater
- [ ] Stove
- [ ] Lighting
- [ ] Other (please specify)

5. How much do you spend on each of the following fuels per month?

	0-100	101-200	201-300	301-400	400+
Wood	Wood 0-100	Wood 101-200	Wood 201-300	Wood 301-400	Wood 400+
Paraffin	Paraffin 0-100	Paraffin 101-200	Paraffin 201-300	Paraffin 301-400	Paraffin 400+
Electricity	Electricity 0-100	Electricity 101-200	Electricity 201-300	Electricity 301-400	Electricity 400+
Gas	Gas 0-100	Gas 101-200	Gas 201-300	Gas 301-400	Gas 400+
Candles	Candles 0-100	Candles 101-200	Candles 201-300	Candles 301-400	Candles 400+
Generator					

0-100	101-200	201-300	301-400	400+
Generator 0-100	Generator 101-200	Generator 201-300	Generator 301-400	Generator 400+

11. What is your knowledge of free basic electricity?

- ○ Aware and receiving it
- ○ Aware but not receiving it
- ○ Not aware

12. What is your view on the cost of electricity?

- ○ Too expensive
- ○ Expensive
- ○ Affordable/Fair
- ○ Cheap
- ○ Too cheap

13. If electricity was free, would you rely on it completely for all your energy needs?

Yes ______________________

No, (please state why not) ______________________

14. What challenges do you face with your currently used fuels?

____

15. What other energy needs or external activities do you have that cannot be met with the available fuels?

Energy Efficiency

What is your level of knowledge energy-saving and energy efficiency?

- Never heard of it
- Heard of it but no understanding of the concepts
- Fair understanding
- Fully understand and apply the concepts

Do you have any energy efficient appliances?

- Yes
- No
- Don't know

Does energy efficiency or energy rating play a role on which appliances you purchase?

- Yes

○ No

What are the energy efficiency solutions you practice in your household?

What effect does the energy efficient solution have on your electricity bill?

○ Lowers the bill

○ None observed

○ Increases the bill

○ Don't know

What practices have been effective in reducing your monthly electricity bill?