Development of a Conceptual Framework for Adoption and Sustainable Utilisation of Biogas as an Alternative Source of Energy for Emission Reduction in Limpopo Province, South Africa

Solomon Eghosa Uhunamure

May, 2019

Development of a Conceptual Framework for Adoption and Sustainable Utilisation of Biogas as an Alternative Source of Energy for Emission Reduction in Limpopo Province

By

Solomon Eghosa Uhunamure

Student No: 11628307

A research thesis submitted to the Department of Geography and Geo-Information Sciences in fulfilment of the requirements for the degree of Doctor of Philosophy (Geography) in the School of Environmental Sciences, University of Venda.

Promoter: Dr Nthaduleni Samuel Nethengwe

Co-promoter: Dr David Tinarwo

May 2019.

TABLE OF CONTENTS

DECLARATION

I, Solomon Eghosa Uhunamure, hereby declare that this thesis submitted to the Department of Geography and Geo-Information Sciences for the award of the degree, Doctor of Philosophy in Environmental Sciences at the University of Venda, has not been previously submitted for a degree at this or any other institution. This is my work in design and execution, and all referenced materials contained herein have been duly acknowledged.

Signature ____________________ Date: ________________
Solomon Eghosa Uhunamure

Signature ____________________ Date: ________________
Dr Nthaduleni Samuel Nethengwe
Promoter

Signature ____________________ Date: ________________
Dr David Tinarwo
Co-Promoter

DEDICATION

To my daughter Victoria Eghosa Uhunamure, I wish her all my blessings as she grows and strives into the world of academia. The study is in memory of my late father and friend, Pa Francis Uhunamure.

ACKNOWLEDGEMENTS

Heavenly thanks to God almighty for the opportunity to study and the strength He gave me to walk through the journey and to endure during the course of this research.

The study reported in this thesis could not have been possible without the help of many people and organisations. My sincere gratitude and indebtedness go to my promoters, Dr. Nthaduleni Samuel Nethengwe and Dr. David Tinarwo for their patience, meticulous supervision, cooperation, encouragement, continuous guidance and comments on the drafts, which were fundamental for the successful completion of this study.

My sincere thanks to the Research and Publications Committee of the University of Venda, National Research Foundation (NRF), the South African National Energy Development Institute (SANEDI) and United Nations Industrial Organization (UNIDO) for their financial support during the period of this research.

I also acknowledge the cooperation and patience of my field assistants, Ms. Nkhensani Manganyi and Ms. Baloyi Ripfumelo Pracious and the respondents of the sampled households, particularly those who endured without complain during the time of administering the questionnaires and interviews. Their valued participation and involvement immensely contributed in the shaping of this thesis.

Further appreciation is extended to my friends and colleagues for their encouragement, assistance and valuable inputs, especially from Prof and Mrs. Emmanuel Oseifuah, Dr. Aniekan Edet, Dr. Tonna Ayansi, Dr. Joshua Edokpayi, Mr. Samuel Ojarikhre, Mr. Zongo Kom, Mr. Tunde Durowuju, Mr. Olujimi Osidele, Mr. Solomon Tunde Ojelade, Mr. Tunde Olaokun and Mr. Frank Moffart. To my dear Ghanaian friends turned brothers I met in Greece, Mr. Ben Agyemang and Mr. Philip Kwaku Freitas; thanks so much for your help. May almighty God continue to reward both of you abundantly.

To my Mom Mrs. Esther Uhunamure, my Bothers (Sunnyson, Alex, Owen and Innocent) my Sisters (Felicia, Florence, Mercy, Vivian), and Mr. Godwin Ikponwonsa, Mr. Kingsley Osagie, M.r Uche, Mrs. Joy Iraha Uhunamure, Mrs. Osayomwanbo Uhunamure and my nieces and nephews; thank you, love you always.

University of Venda
Creating Future Leaders

LIST OF TABLES

LIST OF FIGURES

LIST OF OUTPUTS

Uhunamure, S.E., N.S. Nethengwe and D Tinarwo. 2019. Correlating the factors influencing household decisions on adoption and utilisation of biogas technology in South Africa. Renewable and Sustainable Energy Reviews, 107: 264-273.

Uhunamure S.E., Nethenwge N.S. and Tinarwo D. 2018. Potentials of biogas as a source of renewable energy. A case study of South Africa. International Journal of Renewable Energy Research, 8(2): 1112-1123.

Uhunamure S.E., Nethengwe N.S. and Tinarwo D. 2021. Evaluating biogas technology in South Africa: Awareness and Perceptions at Household Level. In M. Al Qubeissi (Ed), Renewable Energy - Resources, Challenges and Applications. IntechOpen (Chapter proposal accepted).

Uhunamure Solomon Eghosa, Nthaduleni Samuel Nethengwe and Tinarwo David. 2019. The role of biogas technology in fuelwood emissions reduction in South African households. MDPI/Atmosphere Special Issue: Household Cooking and Space Heating: Effects on Air Pollution, Climate Change and Human Health (Article under review).

LIST OF ABBREVIATIONS, UNITS AND NOMENCLATURE

BIOAWA	Biogas Awareness
CBOs	Community Based Organisations
CHP	Combined Heat and Power
EDUL	Educational Level
FWSD	Fuelwood Source and Distance
DFED	Department of Finance and Economic Development
GENDR	Gender
FAO	Food and Agricultural organisation
HHSZ	Household Size
HRT	Hydraulic Retention time
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied Petroleum Gas
NERSA	National Energy Regulator of South Africa
NGOs	Non-Governmental Organisations
NPBD	National Project on Biogas Development
OECD	Organisation for Economic Co-operation and development
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
REWP	Renewable Energy White Paper
SABIA	Southern African Biogas Industry Association
SANEDI	South African National Energy Development Institute
SLC	Subsidies, Loans and Credits
SNV	Netherlands Development Organisation
TECHAVAB	Technical Availability
USD	United States Dollar
UNDP	United Nations Development Programme
WATERASD	Water Availability, Source and Distance
WB	World Bank
WHO	World Health Organisation
ZAR	South African Rand
^0C	Degree Centigrade
C	Carbon
CO_2	Carbon dioxide
CH_4	Methane
GHGs	Greenhouse Gases
GTZ	German Organisation for Technical Cooperation

GW	GigaWatt
GWh	GigaWatt hour
GWP	Global Warming Potential
IEA	International Energy Agency
kg	kilogram
m^3	Cubic metre
m^3/a	Cubic metre per annum
Mg/a	Megagram per annum
MJ	Megajoule
mm	Millimetre
MW	Megawatt
MWh/a	Megawatt hours per annum
Mtoe	Million Tonnes of Oil Equivalent
N_2O	Nitric Oxide
ppm	Parts per million
t	Tonnes
TJ	Terajoule

ABSTRACT

Improved access to modern affordable, sustainable and reliable energy supply is fundamental in the development of any economy and in the achievement of sustainable development goals. However, energy as a resource is increasingly and becoming scare in many countries and subsequently expensive, with a substantial impact on the socio-economic progress, especially in any country that lacks the financial, physical, social and human capital to secure its energy supply. Energy can also be produced though the anaerobic fermentation of biological waste, such as animal excrement, which is methane-rich. Fermentation also produces a nutrient-rich digestate. Biogas can be used for domestic purposes, such as cooking and heating. Furthermore, it can be converted into electricity. Biogas technology is of particular significance in rural households, where energy crisis are common. This thesis therefore aimed at developing an adoption and sustainable utilisation framework of biogas as an alternative source of energy for greenhouse gases emission reduction in the Limpopo Province. The sample involved 72 households with biogas digesters, which were purposively sampled and 128 households without digesters, which were randomly selected. The study was based on the primary data that were elicited using open and closed-ended questionnaires. Empirically, the results of this thesis developed a sustainable, simplified, appropriate and comprehensive framework for biogas adoption and utilisation, including an analysis of important factors that could influence the adoption of this desired technology, for cost-effectiveness and sustainability.

Keywords: Anaerobic fermentation; conceptual framework; digesters; Limpopo Province; logistic regression; sustainable energy;

CHAPTER 1

INTRODUCTION

In any country, one critical necessity in the economic sector is energy. Energy plays a prominent role in enhancing sustainable and inclusive energy growth (Negro *et al.,* 2012). Energy does not affect economic growth alone, but also has a subtle effect on environmental, human, and social developmental aspects (Amigun *et al*., 2011). Access to sustained, affordable, and adequate energy service plays an important role in reducing poverty, improving human health, gender balance, increasing agricultural production, creating competitiveness as well as promoting the general economic growth of the country. In research, a strong bond exists between energy consumption and economic development. Fossil fuel contribution to world energy development is noted and well documented. However, due to accelerated changes in global weather which have resulted from greenhouse gas emissions that have reached alarming proportions in the last few decades. Globally, most governments now consider locally available alternative energy source as a way to enhance the development of renewable energy, which is seen as reliable and efficient answer in mitigating the climate change impacts (UNDP, 2011).

1.1 An Overview of South Africa Energy Sector

The energy sector is critical to South Africa's economy, as the country relies on its large-scale energy-intensive coal mining industry. In addition, the country has limited proven reserves of oil and natural gas and uses its large coal deposits to meet most of its energy requirements, particularly in the electricity sector. In Africa, South Africa has the highest energy consumption, accounting for 30% of the total energy consumption. Furthermore, coal dominates the indigenous resource base of South Africa's energy needs as its source of primary energy consumption, coal accounts for about 89% of this proportion. The use of coal in the country's economy stands at 62% for electricity generation, 23 % in the petrol-chemical industries and metallurgical purposes, and 4% is sold locally or exported by merchants. Owing to near absence and other suitable alternative sources of energy, the significance of coal is unlikely to change in the future in South Africa (DoE, 2015). As a result, dependence on coal has led the country to become the leading carbon dioxide emitter in Africa, accounting for 40% of the total emissions of the continent and the 13th largest emitter in the world (Boden *et al.,* 2011). Remarkably, South Africa has done very well since the post-apartheid era of 1994, by trying to ensure that every household from the poor to the wealthiest has access to modern energy. By 2025, the country aims to provide universal access to modern energy for 97% of the households (DoE, 2015). The government's intention of electrifying all households is to ensure that the citizens' energy basic needs are met, in order to promote social development and economic growth in the country. For the vulnerable and poor, access to affordable, reliable and clean modern energy is vital for improving the human wellbeing and welfare, creating income possibilities, building resilience to extreme weather impacts, such as cold, heatwaves and reducing dependency of households on natural resources, such as fuelwood (Statistics South Africa, 2011)

South Africa is endowed with different energy sources, such as wind, solar, hydro, nuclear, biomass and geothermal. The sources of energy in the country are broadly classified into three categories; namely, traditional sources such as biomass, commercial and alternative sources. The traditional sources of energy include fuelwood and other agricultural residues, used as domestic waste. Under the commercial energy sources, there are petroleum products and electricity, while the alternative energy sources include renewables such as solar and biogas energy.

In many developing countries, some conventional sources of energy are over-depended upon substances such as fossil fuels and fuelwood as economic drivers for development. Heavy dependence on biomass in most developing countries has raised concerns globally over its environmental impacts such, as soil erosion, forest degradation and the negative health consequences associated with indoor air pollution, resulting from the burning of fuelwood and agricultural residues. The relationship between fuelwood collection impacts on livelihood, specifically, in rural areas impact negatively on the sustainable development of forest resources, which has put forests under threats from the increasing fuelwood consumption (Madubisi and Shackleton, 2006). Fuelwood is regarded as one of the most dominant solid fuels and has been the main energy source for domestic households in the predominantly rural parts of the country. In rural households, the use of fuelwood as an energy source for cooking and space heating stands at 74% and 24% in urban households (DoE, 2013).

Annually, the estimated total fuelwood consumed by South Africa households is at 11.2 million tons, which is equal to 52 889 GWh or 190 400 TJ. This represents 40% of the total energy consumed by households in the country (Damm and Triebel, 2008). Approximately, 2.3 to 2.8 million households rely on fuelwood for heating and cooking purposes. This thus translates to 4.5 tons per household per annum (Damm and Triebel, 2008). According to Muye (2015), in Africa, cooking on open fire is a norm in most cultures; thus, in most rural households, cooking in open fire is still one of the most prevalent method of cooking in South Africa. The use of open fires for cooking has a low energy efficiency in the range of 3 to 8%, which means about 97 to 92% of the total energy is lost to the environment. The loss of energy in open fires is attributed to its low heat transfer, which is due to high losses to the ground (Muye, 2015).

Energy efficiency has a significant potential to save money in South Africa and also acts in its energy mix, by increasing the share of renewable energy. Presently, 93% of the nation's electricity is generated from coal, with 85% of the population having access to electricity, which is predominately in the rural areas (World Bank, 2016). The energy crisis of 2008 propelled government to introduce renewable energy on a larger scale, coupled with promoting energy efficiency in all sectors of the economy, while also reducing the emission of carbon dioxide. To mitigate climate change, increasing the diversity of the country's power generation mix is important, as it could also enhance the security of energy supply (DoE, 2015).

South Africa introduced the Renewable Energy White Paper (REWP) in 2003, which was developed by the Department of Mineral and Energy, with a set target for renewable energy contribution to the energy mix of the country. The department also mandated by REWP to develop a practical strategy for the application of renewable energy potential that would immensely contribute to the energy sector of the country (Pegels, 2010). The Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) was introduced in 2011, with the mandate to harness energy from renewable sources, with an initiative to install 17.8GW of renewable energy before the year 2030. The aim was to achieve drastic reduction in greenhouse gas emissions, by abating reliance on non-renewable energy sources such as coal. The REIPPPP was also mandated to work on promoting local materials in the renewable energy manufacturing sector (Walwyn and Brent, 2015).

1.1.2 The Energy Sector as an Engine of Socio-Economic Development

Energy is one of the basic and fundamental requirements that sustains human life. However, many people in rural areas do not have adequate access to efficient and affordable energy resources. For example, the vast majority of rural people are dependent on traditional fuel, such as wood, dung and crop residues, and often use it with primitive and inefficient technologies. For many, a combination of these, rarely allows for the fulfilment of the basic human needs, such as nutrition, warmth and light, let alone the possibility of harnessing energy for productive uses, which might begin to allow them to break the cycle of poverty (WEC, 2003).

The foundation of modern economy is energy. This is because it forms the ingredient, which is essential for almost all human activities. Energy provides services for transportation and industrial production, health, education, lighting, food production, water heating, space heating and mineral extraction, among others. Furthermore, energy services are influential drivers in socio-economic development, as no country has succeeded in developing beyond subsistence economy without the provision of at least the minimum energy access to the broad section of its population (Stern 2011).

There are many facets of poverty in developing countries. One such facets, is how to cope with limited means and lack of efficient household energy technologies. In most rural communities in Sub-Sahara Africa (SSA), poverty can mean, among other things, having to rely primarily on wood and or dung for cooking and heating. According to Masekoameng *et al.,* (2005), as in many other developing countries, rural areas in South Africa are less privileged in terms of social services and infrastructure, compared to urban centres. Where services are available in these areas, they are normally of low quality and limited. Even the energy consumed in the rural areas is mainly from traditional sources such as fuelwood and cow dung.

1.1.3 Importance of Biogas as a Source of Renewable energy

South Africa is endowed with diverse energy sources and these include solar, wind, biomass, geothermal fossil fuel, and hydro. These energy sources can be classified broadly into three groups; namely, commercial, traditional, and alternative sources. Included in the commercial source are petroleum products and electricity. The traditional sources are agricultural residues, paraffin (kerosene) and fuelwood. They are used mainly for domestic purposes. The alternative sources are biogas, solar and wind among others.

Through the White Paper Policy on Renewable Energy, the South African government has opined on a new trajectory on sustainable development and growth, with an expected contribution of 17 800 MW of energy from the renewable sector, in order to reduce the consumption of coal, thereby lowering the emission of greenhouse gases in the country. As identified by the government, renewable energy is crucial in advancing and transforming the energy sector, while also providing social equity for all. It is also expected that renewable energy will contribute towards creating green jobs in the economy, offer access to modern energy carriers and diversify the country energy mix by the year 2025 (DoE, 2015).

The much-desired revitalisation of sustainable rural energy in developing countries can be achieved through renewable energy such as biogas. It is a less expensive option and ideal alternative for low income communities because it is affordable, locally available and easily accessed, as well as being used and managed by the local communities. The process of biogas technology is through anaerobic digestion, which is produced using biodegradable materials such as animal dung, human waste and agricultural residues. In large quantities of municipal, agricultural and industrial solid wastes, anaerobic digestion of biogas can be used for heat and electricity generation too. Wate can also be used as agricultural fertilizers. The digester systems are comparatively simple, economical and can be operated from small to large scales in rural and urban locations. In this respect, many governments and non-governmental organisations have recognized that renewable energy can play a very vital role in augmenting the existing energy sources (Amigun & von Blottnitz, 2007).

The use of biogas systems offers multiple benefits; for example, in the process of anaerobic digestion, the organic nitrogen in the manure is largely converted to ammonium. Ammonium is the primary constituent of commercial fertilizers, which is readily available and utilised by plants. Biogas systems can reduce offensive odours from overloaded or improperly managed manure storage facilities, which can impair on air quality. Thus, the use of this system reduces offensive odours through the volatile organic acid content; as the biogas-producing bacteria consumes the odour-causing compounds (Hill and Bolte, 2000). Biogas is a flexible energy carrier that is suitable for many different applications. One such application is direct use for cooking and lighting. Furthermore, it is simple and reasonably efficient to use the gas directly in conventional low-pressure gas burners (Hill and Bolte, 2000). However, nowadays, in many countries, biogas is used for Combined Heat and Power generation (CHP) or upgraded and fed into natural gas grids, used as vehicle fuel or in fuel cells for other energy-related activities (Hill and Bolte, 2000).

The experience of biogas in Africa has been on a far smaller scale and has been disappointing generally at the household level. Furthermore, the capital cost, cost of maintenance, and management support required have been higher than expected. Moreover, under subsistence agriculture, access to cattle dung and water that must be mixed to form the slurry has been more of an obstacle than expected. Nevertheless, there are better possibilities where farming is done with more actively managed livestock and where dung supply is abundant, such as rearing feedlot-based livestock (Kammen, 1999). The enthusiasm for initial biogas development in Africa has thus been somewhat dampened by experience because of the requirement of relatively large amounts of animal dung. Thus, the niche for household biogas plants is likely to remain small. Besides, poor families do not have access to sufficient dung, and better-off families with sufficient animals often prefer to purchase fuel and fertilizers rather than spend time gathering dung and managing the often-temperamental digesters. Nevertheless, in the right institutional and social context, and coupled with appropriate technical expertise, the potential for biogas remains significant (Kammen, 1999).

The technology of biogas production as a form of renewable energy has become a global concern over the past decades. Biogas is a methane-rich gas produced through the anaerobic fermentation of organic materials, which is distinct from other renewable energy sources, such as solar, wind, thermal and hydro (Pereira, 2009). The role of biogas in the reduction of greenhouse gas emissions and improving the security of energy supply in households, especially where they have some challenges in energy source and supply, is widely accepted.

In addition, biogas energy has formidably positive environmental properties, resulting in no net releases of carbon dioxide and very low sulphur content (Erdogdu, 2008). The technology can also lead to a reduction in greenhouse gas emissions (Han *et al.,* 2008). A proper functioning system can also provide multiple benefits to the users and the community, resulting in resource conservation and environmental protection (Yadvika *et al.,* 2004).

Biogas energy use makes a significant contribution to the security of energy supply sustainability. This is because reliance on imported fuels, especially fossil fuels, threatens the essentials of sustainable development because they are unreliable, expensive, and exhaustible. Bioenergy not only contributes to energy diversification strategy, but also the substitution of energy imports, making it an important energy source for economic and national security reasons (Erdogdu, 2008). With respect to energy, it is clear that in the near future renewable sources will play a more significant role (Iniyan and Jagadeesan, 1997) than the conventional energy sources. Akpinar *et al.,* 2008 reported that in future, biogas energy would play a significant role in producing green power in the world. Bioenergy thus presents an opportunity to move towards more decentralized forms of electricity generation, where a plant is designed to meet the needs of the local consumers, while avoiding transmission losses and increasing flexibility in system use. This, in turn, provides an opportunity to increase the diversity of power generation plants and competition in energy generation within the economy (Erdogdu, 2008).

1.2 Statement of the Research Problem

Fundamentally, energy poverty remains a serious challenge because it is critically a component of economic development, environmental and social growth which form a central part of any country's development. Globally, most governments are considering locally-obtainable, renewable and alternative energy options and the need for the provision of cleaner energy and security. Fossil fuel combustion contributes greatly to carbon dioxide emissions, which is the main greenhouse gas that has been linked to climate change. Reliance on fossil fuels to meet the energy requirements are recognized. However, as concerns about climate change grow, there is a need for the provision of alternative energy, preferably renewable energy.

There is increasing interest in renewable energy sources in South Africa. This interest has been compelled particularly by the increasing magnitude of energy demand in urban and rural settlements. In addition, there are existing supportive policies on rural energy investments and institutional mechanisms that have been built through earlier work by the government and private sectors in the country. Thus, the energy crisis being witnessed in the country provides a conducive entry point for an integrated household-level biogas programme, among other alternative renewable energy. In addition, there are existing and favourable conditions for the production of biogas energy. These include the availability of abundant biodegradable animal and crop waste materials, such as in Limpopo Province.

Evidently, most rural households in Limpopo Province rely on fuelwood as their primary source of energy, mostly for domestic purposes. However, modern and cleaner sources such as electricity and liquefied petroleum gas (LPG) are available but expensive, putting them out of reach of the populace, while other renewable energy sources which are environmentally friendly have not been sufficiently exploited. Most households now rely on fuelwood harvesting to meet their domestic needs particularly, cooking and heating. However, this poses a health challenge and environmental risk. Moreover, the demand for fuelwood has consequences on the surrounding forest, leading to wood depletion, degradation, disturbance of the ecosystem and reduction of the forest capacity to sink carbon.

The continual combustion of fuelwood, particularly the products of incomplete combustion, also contributes to indoor air pollution in households with poor ventilation and also increases the incidence of respiratory ailments amongst the users, such as asthma, eye irritation as well as damage to the skin due to excess heat produced when the wood is burnt. Biogas can therefore provide clean, sustainable and affordable energy to rural dwellers, mostly for domestic purposes. Despite the numerous advantages, coupled with demonstrated experience of biogas production and utilisation as a renewable energy source and as good waste management strategy, the energy potential of the technology has not been fully tapped. This is because the influencing factors that propel some households in adopting the technology and others not adopting it remain unclear.

The development and utilisation of this desirable, modern, ecology-oriented and friendly form of appropriate technology remain low and its adoption remains dismal. Around the world, the technology has been advanced as renewable energy option and for the reduction of greenhouse gases. Biogas energy adoption and utilisation still do not have a foothold at household level due to a multitude of intertwined factors. As a result, the socio-economic potential has largely remained elusive because of the level of awareness and perceptions of the technology. Thus, the level of adoption and utilisation is presently not commensurate with the technology potential. A number of studies related to biogas technology ranging, from technical aspects to status reviews, exist in South Africa. Biogas production optimization from different substrates and types of biogas digesters, problems, challenges and solutions of the technology have been studied by Msibi and Kornelius, 2017; Nekhubvi and Tinarwo, 2017; Mutungwazi *et al.,* 2018; Okudoh *et al.,* 2014; Mukumba *et al.,* 2016 to mention but a few.

However, most technology innovation and development efforts rarely address the socio-cultural challenges of effective technology diffusion and sustained acceptance. In the case of Eseonu and Egbu, 2014, on socio-cultural influences on technology adoption and sustainable development, the approach was unimodal, which are not adequately enough in the case of disseminating a technology like biogas. A resolution to adopt a technology differs and varies based on the roles played by the household resource endowments, socio-cultural, economic, environmental, and technical factors. For technology adoption to be successful, the involvement of the region-specific, socio-economic and cultural factors need to be considered, as these have not been sufficiently explored from a household perspective. The contribution of biogas technology in the reduction of greenhouse gases emissions, through high level adoption and utilisation in household energy sector has not been widely and properly studied, quantified and documented. More so, government and private sector participation in the dissemination of this technology has not been effective. The reasons for these trends largely remain obscure and unexplored.

1.3 Research Aim and Specific Objectives

1.3.1 Research Aim

The main aim of the study was to develop a conceptual framework that will enhance the adoption and utilisation of biogas technology as an alternative source of energy for emissions reduction in the rural settings of Limpopo Province.

1.3.2 Specific objectives

- To evaluate household levels of biogas awareness and perceptions towards the adoption of the technology;
- To determine the correlating factors influencing the sustainable adoption and utilisation of biogas technology in the rural areas of Limpopo Province;
- To estimate the quantity of greenhouses emitted from fuelwood use in the study area and determine how much of this would be reduced through the adoption and utilisation of biogas technology and
- To develop a conceptual framework for the adoption and sustainable utilisation of biogas technology in the province.

1.4 Research Questions

- What are the household levels of biogas awareness and perceptions towards the adoption of the biogas technology?

- What are the correlating factors influencing the sustainable adoption and utilisation of biogas technology in the rural areas of Limpopo Province?
- What is the quantity of greenhouse gases emitted from fuelwood in the study area and how much of this will be reduced through the adoption and utilisation of biogas technology?
- Which conceptual framework is suitable for the adoption and utilisation of biogas technology in the province?

1.5 Hypotheses

The following hypotheses guided the study:

- Multiple factors influence the adoption and utilisation of biogas technology.
- Users' level of awareness and perceptions play an important role in a household's choice of energy sources.

1.6 Delimitation of the Study and Description of the Study Area

1.6.1 Delimitation of the Study

The focus of this study was to develop a conceptual framework for the adoption and utilisation of biogas technology as an alternative source of energy for emissions reduction in rural South Africa villages, using Limpopo Province as a case study. The study focused on factors affecting the adoption and utilisation of the technology and aimed at developing a framework, to increase the adoption and utilisation of the technology focusing on the people's awareness and perceptions of the technology were evaluated. In addition, the correlating factors influencing the sustainable adoption and utilisation of biogas technology in Limpopo Province were determined. The amount of greenhouse gases emitted from the consumption of fuelwood in the study area and how much will be reduced from the adoption of the technology are estimated.

The greenhouse gases considered in this study were carbon dioxide (CO_2), methane (CH_4) and Nitrous oxide (N_2O). Global warming, which has the potential to cause climate change, is caused by emissions of greenhouse gases such as carbon dioxide, methane, nitrous oxide and other chlorofluorocarbons. From the total gases emitted, carbon dioxide, methane and nitrous oxides are significant components of the atmosphere because of the total greenhouse gas emitted: 67% is carbon dioxide, making it the principal cause of global warming. Carbon dioxide is released into the atmosphere through natural processes such as respiration and volcanic eruptions, as well as through anthropogenic activities such as deforestation, burning of fossil fuels and biomass and land use changes. Carbon dioxide remains in the atmosphere for about 100-200 years. In addition, its concentration increases as it mixes with other gases, which in turn raises the average temperature of the earth. The percentage of methane emitted into the atmosphere is 18% but it is 21 times more potent than carbon dioxide, while nitrous oxide is about 7%. The study did not consider other areas, such as the genes or bacteria from different feedstock or biodegradable materials that could improve the optimization of the technology, mathematical modelling of the technology, computer stimulation, microbial level of different substrates and other areas considered as out of the scope of study.

1.6.2 Description of the Study Area

Limpopo Province is one of the nine provinces in South Africa. It is located in the Northern tip of the country. Figure 1.1 shows the map of the province and the study areas.

1.6.2.1 Location

The province lies between coordinates 23° 40' 13.81"S longitudes and 29° 41' 79.90"E latitudes. Limpopo Province is the northern-most province of South Africa, lying within the curves of the great Limpopo River. It shares international borders with Botswana to the west, Zimbabwe to the north and to the east, Mozambique. In the south, from east to west, the province shares its border with Mpumalanga, Gauteng, and the North West Provinces. With its shared borders, the province is regarded as the gateway to the rest of Africa, making it economically favourable with other southern parts of Africa continent. Contained in the province is much of the biospheres such as the Waterberg biosphere, a massif of 15,000km^2 approximately, shaped by millions of years of diverse yield bluff and buttle landforms from riverine erosion, which is a United Nation Scientific and Cultural Organisation Biosphere Reserve. The province is divided into five municipal districts; namely, Capricorn, Mopani, Sekhukhune, Vhembe and Waterberg, and further divided into twenty-five local municipalities.

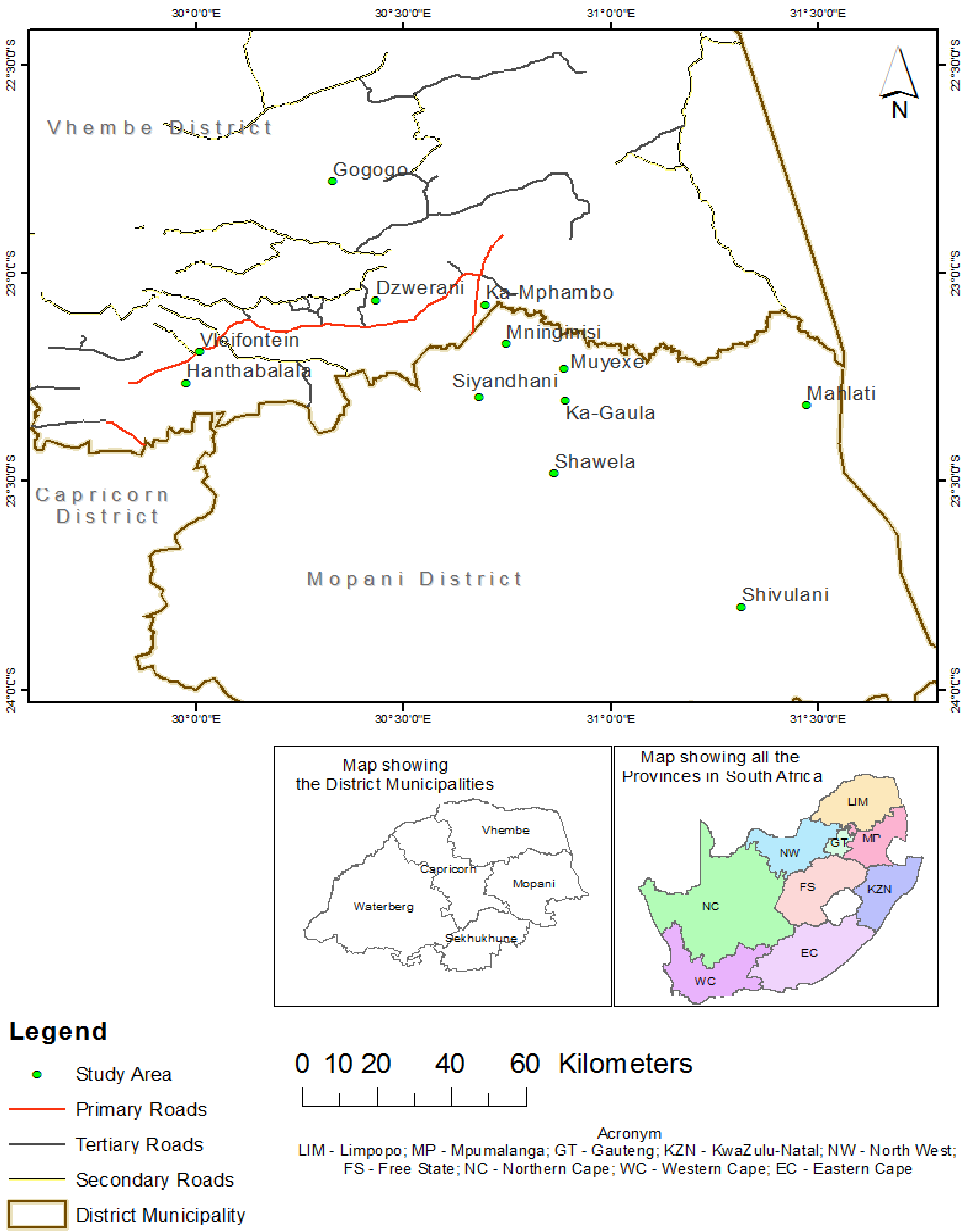


Figure 1.1: Map of Limpopo Province, showing the study areas (Source: Author, 2017).

1.6.2.2 Climate

The province's climate spatially varies from being arid in the west, semi-arid in the east and temperate areas in the central zones. It offers extremely hot conditions, as it is intersected by the tropic of Capricorn, with all-year sunshine. The climate type falls within the sub-tropical climate, with an average rainfall of 300-1000 mm per year (South Africa Channel, 2010). During the summer months, the heat is often interrupted by rainfall and short thunderstorms (October to March) average temperature can range between 27º C to as high as 45º C. The mountainous areas receive an enormously amount of rainfall yearly, with an average significance of about 1329 mm (M'Marete, 2003). Annually, the evaporation rate increases gradually from 1400 mm in the west to 1900 mm in the east of the province.

In the winter period (May to September), mist occurs frequently in the mountainous areas. The weather at night is characterised by cold and is mostly frost-free, with chilly mornings, dry and sunny days, with an average temperature of 4° to 20°C. The seasonal average humidity falls within 80% in the summer and about 38% in the winter (M'Marete, 2003).

1.6.2.3 Topography and Drainage

The plateau of the province and the eastern Lowveld form the two basic physical subdivisions, which are significantly different in every aspect with respect to attitude, vegetation, landform and climate. Between these two areas is the boundary of the Great Escarpment, which is of geographic importance. The erosional trough and tectonic of Limpopo is a significant feature that causes a disruption in the escarpment and forms a momentous depression westward into the plateau. The terrain patter of the province is broad and characterized by plains, forming to the northern part and the Bushveld basin, surrounded by the Central highland which is bordered eastward by the Great Escarpment and the Eastern Plateau slope (Limpopo DFED, 2004).

There are two main drainage regions dividing the province. One region includes all the rivers draining to the north and into Limpopo River, while the other includes the Olifants river basin, which confluences eventually with the Limpopo River in Mozambique. A small portion drains into the Komati/Crocodile catchment, located in Mpumalanga. In the north and east, there are a number of prominent rivers with high flow systems from the Drakensberg Escarpment with high rainfall. These are characterised by the river systems. The system, with high flow, includes the Klein Letaba river with its tributaries (Molototsi, Nsami and Middle Letabe, the Great Letaba River (Thabinal) and Selati and Blyde as well as the Olifants River (Limpopo DFED, 2004).

Of significance also are the areas with run-off-rivers that are stable and largely afforested, such as the Thabina Dam areas and low run-off flows, which are without major impoundment and reach the upper Letaba River Basin in the high-yielding streams of the Drakensberg. Two regional water systems are significant in the north. These are the Levhuvhu and Mutale rivers. In the south, surface water is mainly limited to two river systems, namely, the Olifants and the Stillport Rivers. The Mohlaletsi, Mohlapitsi, Motse, Motsephiri and Nkumpi rivers are the main tributaries of the Olifants River. In the western part of the province, the Sterk River occurs as the major river system. Mopogodima, Chinues and Mogalekwena rivers are the significant rivers in the central part of the province (Limpopo DFED, 2004).

1.6.2.4 Soil and Vegetation

The province is predominantly covered with soil derived from sandstones and quartzite, which are generally well drained, shallow and gravelly and low in nutrients but acidic in nature (Mucina and Rutherford, 2006). The soil types that occur in the province are related to the parent materials that characterise the surface areas in which it is deposited and it is influenced by climatic conditions of rainfall and the hydrological systems. Varieties of soils are found in the province that are differentiated based on the depth, materials and the diagnostic nature of the horizons. Arable soils are determined based on combinations of the slope angle and depth of the soil, with a broad soil group in the entry of each land type (Limpopo DFED, 2004).

The natural forest consists of small to large forests and forest complexes arising in the isolated pockets at Blouberg Mountains and along the Southpansberg Mountain and the North-Eastern Drankensberg Escarpment. Limpopo Province falls under the greater-savannah biome, which is commonly referred to as the bushveld, with grassland of small representation and forest biomes. Greatly enhanced in the province is diverse flora, which is influenced by the topography. The bio-geographical location attitudinal ranges, geological formations, climatic influence and soil have influenced the high communities of species diversity and distribution in the province. The vegetation types are of critical importance and require conservative representation for the preservation of the flora diversity as over one third of the forest is in a state of decline is due to over-exploitation and utilisation of the forest resources. The importance of the forest is mainly for their ecological functions, which include biodiversity protection (Limpopo DFED, 2004).

1.6.2.5 Population and Economic Activities

Limpopo Province covers a total land area of 125 755 square kilometres and has an endowed population that is culturally mixed, with about 5.27 million people representing 12% of the national population. Predominantly, the province is rural and accounts for the highest level of poverty, with 78% of its population living below the national poverty line. In 2011, 74.4% of its population locally lived on tribal or rural areas, which were typically located in tribal traditional areas or former homelands, compared to the national average of 27.1%. The home languages principally spoken are Sesotho, Xitsonga and Tshivenda (Statistics South Africa, 2011). Generally, the patterns of commuters are from the rural villages to established towns and commercial farming areas with the Southern and Lowveld districts showing a commuting pattern south into the neighbouring provinces (Limpopo DFED, 2004).

The province is a typical developing area, exporting primary products and relying on imported finished goods and services. It is also one of the poorest regions of South Africa, with an immense gap between poor and rich residence, especially in rural areas. Although, it has shown pronounced development in the economy and standard of living, it is still low compared to the national average. The type of houses comprised of clay walls and thatched roofs, as well as cement walls and corrugated iron roofs. The settlements are characterised by unequal access to basic amenities and unequal distribution of land resources, as well as inadequate infrastructure, high unemployment rates and few job opportunities, particularly in the rural villages. Most of the households in the rural areas, which comprise much of the population of the province, depend on pension grants, government grants, and remittances from family members who migrate to other provinces to work. The household wealth is relatively lower, compared to other municipalities in South Africa (Aaron and Muelbauer, 2006).

The people in the province are renowned for agricultural practices in both commercial and subsistence production. The major land uses of the area are agriculture and mining. The sub-tropical climate that prevails over the area gives rise to conditions favourable for the cultivation of sunflower, peanuts, maize and cotton in the Bela-Bela and Modimole axis. However, in the Tzaneen and Louis Trichardt axis, tropical fruits are grown. Examples of these are mangoes, pawpaw, bananas, and litchis. Tea, citrus, coffee, pineapples and oranges are also grown on a large scale. Large vast of the province land are used also for animal grazing and livestock, which roughly stand at about 81% and 10.5% used for agriculture. However, about 90% of the land is used together by both commercial and small farmers in the province (Maluleke *et al.,* 2016). Livestock farming, which includes cattle ranching and game hunting, is also paramount in the province. Though regarded as one of the poorest provinces in the country, with problems of socioeconomic that persist in the rural parts characterised by high unemployment rate, the province remains one of the lowest in the country, with a low average in terms of annual household income (Statistic South Africa, 2015). The rich wildlife gives it an edge in attracting tourism as both the private and public sectors are investing in the development of tourism (Limpopo DFED, 2004).

1.7 Significance and Justification of the Study

Challenges faced by the citizenry of South Africa, particularly those in the rural areas, include the provision of energy that is affordable and accessible, that will be environmentally friendly on a large scale. The efforts to promote renewable energy technologies in South Africa need to be supported following the recognition of energy crisis particularly in rural areas. These are the areas threatened by deforestation due to fuelwood harvesting; hence, the residents of these areas are victims of domestic energy crisis. Biogas technology as an alternative renewable energy source has been available in South Africa for some time now. However, so far, the technology has not been fully adopted to the expected levels, resulting in the continued exploitation of the forests and its resources to supplement the energy needs of the populace.

The growing concern about climate change, rising energy cost and demand, cost of fertilizers, labour and time incurred in the collection and harvesting fuelwood in the rural areas. The use of biogas technology, can be a significant alternative in the use of traditional fuels. This is because biogas can provide clean and cheap energy that is free of particulate, incomplete combustion and reduces the chances of ailments associated with the use of traditional biomass, while improving soil fertility through slurry.

Anaerobic digestion can significantly lower the emissions of greenhouse gas from animal dung, solve problems of sanitation by improving the farm hygiene, as the province is greatly associated with domestic rearing of animals. This can be transformed into energy that could help in mitigating household demand. Biogas adoption and utilisation also have robust benefits in terms of public health and mitigation of climate change through the provision of cleaner energy and reduction of collecting, harvesting and consumption of fuelwood.

The findings of this study will contribute to a better understanding of the causes of low adoption rate of the technology. With support from Government institutions and other stakeholders to adequately promote biogas technology, many people will adopt it as an alternative sustainable source of energy. Biogas adoption and dissemination of the technology will reduce deforestation, save time wasted in fuelwood collection and in turn increase the people's participation in other productive work. Organic fertilizer yielded as the by-product of the technology will improve crop yields, hence enrich the lives of the users.

Furthermore, policy makers, planners, and non-governmental organisations in respect of renewable energy could use the findings of this study as input for decision-making. It could also expose some areas that need improvement as far as developments of biogas programmes are concerned, and provide additional knowledge on the present literature on bio-energy technologies about the potential of agro-forest residues to be used as raw materials for renewable energy source. It is also anticipated that the study will also stimulate interest on more studies in the field of renewable energy sources.

1.8 Operational Definitions

The various terms that might occur repeatedly in this thesis are defined below.

- **Biogas:** Typically refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen by the process known as anaerobic digestion. Biogas consists mainly of 50-70% Methane, 30-40% carbon dioxide and low amounts of other gases.
- **Fuelwood:** Includes the free gathering of wood in various forms such as scrap wood, wood wastes from construction sites, woodcraft, lumberyards, forest, landfill or garbage sites including non-woody biomass (FAO, 2010).
- **Household**: According to Statistics SA, a household is a group of persons who live together and provide themselves jointly with food and/or other essentials for living, or a single person who lives alone (Statistic SA, 2011).
- **Socio-economic factors:** It is the social and economic experiences and realities that influence a person's personality and lifestyle (Statistic South Africa, 2011).
- **Technology:** The way people use knowledge, tools and systems to make their lives better and easier.

1.9 Structure of the thesis

This thesis is organised into eight chapters. The first chapter is the Introduction. Chapter 2 covers the reviewed literature related to the study. Chapter 3 entails the methodological approach adopted for the study. Chapter 4 is on the evaluation of biogas awareness and perceptions towards adopting the technology in South Africa households. Chapter 5 determines the correlating factors influencing the sustainable adoption and utilisation of biogas technology in the households of Limpopo Province. Chapter 6, estimates the amount of greenhouses emitted from fuelwood use in the study area and determine how much of this will be reduced through the adoption and utilisation of biogas technology in the study area. Chapter 7, develops a comprehensive conceptual framework for the adoption and utilisation of biogas technology and chapter 8, includes the conclusion, recommendations and contribution of the thesis and suggestions for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature based on the following themes: biogas technology, types of biogas plants, biogas technology adoption, theoretical framework for technology adoption, theory of planned behaviour, diffusion of innovation, adoption processes and factors affecting the adoption processes.

2.2 History of Biogas Technology

There are suggestions that in the 10^{th} century B.C., biogas was used for water heating in Assyria and that in ancient China, solid waste to anaerobic digestion may have been applied from the mid-nineteenth century. Documented attempts by humans to harness the potential of anaerobic digestion of biomass were also recorded in New Zealand and India. Digesters were constructed in Exeter, United Kingdom using sewage sludge digester in the 1890s to fuel street lamps (He, 2010).

The Chinese province of Guangdong has commercially used biogas, built by Guorui Luo. He constructed an 8 m^3 biogas tank that was fed with household waste, and after a decade, he founded a company to promote the technology (He, 2010). The first sewage plant that supplied biogas to the public began operation in 1920, while in 1950, the first agricultural large biogas plant became operational in Germany. However, the spread of the technology gained momentum in the 1970s due to high cost of oil that motivated the use of alternative energy. Many Asian countries recorded the fastest growth, followed by Latin American and the African countries in the late 1970s and in the early half of 1980s respectively (Mshandete and Parawira, 2009). The Chinese government sponsored the use of biogas in every rural families and funded the installation of more than 7 million digesters in the rural villages during the period of the 1980s. Due to success in the application of biogas technology in industrial, conversion of energy and for urban waste treatment, the continued spread to rural areas was slowed and at the end of 1988, only about 4.7 million digesters in households were reported functional (Ni and Nyns, 1996).

However, since the turn of this era, there has been a rapid increase in the number of plants and in 2007, China had over 26.5 million digesters plants, with an overwhelming majority of 6 to 10m^3 systems in the households. In India, during the 1999s, there were well over 3 million biogas plants of family size and at the end of 2007, the government of India had subsidised the construction of almost 4 million family sized biogas plants around the country (Mittal *et al*., 2018). In 1982, the National Project on Biogas Development (NPBD) ran and promoted its own designs of digesters, while also providing financial aid and supports various training and development programmes in the spread of biogas. In 1990, the central and state government provided subsidised the installation of household bioreactors, which ranged from 30% to 100% (Tomar, 1995).

In Europe, Denmark constructed a biogas plant for the treatment of freshwater, which started in the 1920s. Initially, the gas was used to heat up the tank without a purpose not to extract energy, but rather to reduce and stabilize sludge when the organic matter decomposes in the wastewater, which is a treatment in the product process. Nevertheless, shortly after the Second World War and in the following period, Europe witnessed a substantial growth in the biogas industry mainly in Germany, France and Britain and gradually, the technology found its way into agriculture with the production of energy as the main purpose. The development of biogas technology nearly stopped at the end of the 1950s due to the cheapness of fossil fuels, particularly oil and gas and the interest of biogas was rekindled in the mid-1970s following the 1973 oil crisis (Jorgensen, 2009).

Research and development were initiated with the aim of constructing and testing several biogas plants using biomass with animal manure as the main source. Sewage plants that were installed with biogas facilities were well over 60. More than 20 of the plants with various sizes in communal areas treat manure, particularly slurry from livestock farms. Large amounts of organic waste from the slaughterhouses and food industries were used in the plants, whereby energy is extracted from the waste and the nutrients recycled for agricultural purposes. In addition, there are on-farm services that are associated with biogas plants aimed at producing high organic content from landfill sites using different industries. Lack of economic activities stagnated the expansion of the biogas sector in Denmark during the 1990s but the sector is starting slowly due to policy on promoting green energy and for a better price for electricity produced from biogas (Jorgensen, 2009).

Though considered as a good starting point, the rate of dissemination was below expectation and was not convincing, considering the potential market for biogas is some selected countries as targets. Biogas dissemination in Africa is potentially defined by the availability of biomass resources, affordability, and versatility of the climate. Municipal waste, agricultural, forest residues and the number of livestock are the data for potential projection (Smith, 2011). Biogas is considered as a mitigation response to the low level of electrification in rural areas, depletion of forest resources, especially biomass; it improves soil quality and waste treatment; increases agricultural residue, thereby creating sustainable and safe environment. In compliance with safe sanitary and environmental conditions, large to medium households biogas digesters have been installed in several countries, including Rwanda, Burundi, Namibia, Ghana, Nigeria, Burkina Faso, Lesotho, Zimbabwe, Ethiopia, South Africa, Morocco, Tanzania, Uganda, Guinea, Tunisia and Botswana. Biogas digesters utilize varieties of feedstock from slaughterhouses, animal dung, and industrial waste and human excreta. Few biogas digesters have been developed to treat manure from chicken and dairy farms in Burundi, health clinics in Tanzania, public toilets in Kenya and boarding schools and prisons in Rwanda (Mshandete and Parawira, 2009).

In Sub-Sahara Africa, South Africa is unique and advanced in terms of biogas and anaerobic technology because of the high level of economic development and many of the country's universities are endowed with capacities to carry out research regarding biogas. It should be noted that most attempted models in Africa are the household's digesters that are fed mostly with domesticated animal manure. This is because the technology is linked closely to alleviation of poverty for rural development (Smith, 2011).

Biogas plants for domestic purposes were introduced in some African countries some decades ago, with substantial participation in 2008, when NGOs accelerated technology awareness by promoting and disseminating the technology. The national programs and initiatives results showed a significant growth in the numbers of installed biogas digester and technical skills, which were considered an encouraging take-off point for the technology. In nine African countries, about 17 000 digesters were installed and these were supported by the Netherlands Development Organisation (SNV) (Mshandete and Parawira, 2009). In 1957, the foremost experimental biogas plant using pig manure was installed in South Africa (Tiepelt, 2015). Despite the potential of the technology in the country, the level of adoption and utilisation remains low, with well just over 700 installed digesters nationwide (SABIA, 2015). The technology, as reported in South Africa, has a capacity to potentially generate 2.5 GW of electricity from employing waste streams from food waste, agricultural residue, wastewater treatment plants, breweries, cheese factories and commercial processing abattoirs. The technology has a market value of about R10 billion, which can expedite the creation of thousands of jobs for about 300 000 households in the country (Okudoh *et al.,* 2014).

Biogas is considered as an exceptionally suitable form of renewable energy for converting agricultural and other organic waste into biogas. The technology can also contribute to sustainable management of waste and reduction of carbon emission from both waste decomposition and displacing the conventional energy supply. Biogas technology is relevant from large, commercial to small-scale organic waste stream. These scales are all limited in South Africa due to the low level of adoption and utilisation. Smaller-scale biogas digesters, however, are more prevalent in the rural areas of the former homelands, where there is an irregular supply of electricity from the national grid. Due to this lag, the government is looking for mechanisms to encourage the development of biogas technology under a tailor-made, small to large scale in programmes, innovations and developments (DoE, 2017).

Interest in biogas technology is being pushed through regulations, policies, initiatives and involvement of a number government and non-governmental organisation programmes. Such organisations include the South African National Energy Development Institute (SANEDI) and Biogas SA, which are monitoring, directing and conducting innovative researches around the country, while working with academic institutions and science councils in promoting the biogas technology. On other hand, private investment in renewable energy technology is being promoted by organisation such as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). The first biogas industry association, South Africa Biogas Industry Association (SABIA) was formed with the aim of representing and promoting stakeholders interest in the technology (SABIA, 2013).

Worldwide, several designs and types of biogas digesters and plants exist. In South Africa, the developed designs of the last century have however, been mostly adopted. The adopted designs are categorised into domestic/rural digesters and agricultural/industrial digesters. Domestic/rural digesters, which are often small scale and installed in small facilities or households, to generate gas usage, include the Floating drum digesters, Fixed dome digesters, DIY biobag digesters kit and the Deenbandhu digester designs. Agricultural/industrial digesters are in the categories of medium to large scales digesters, with an electricity power generating capacity of between 25 and 400 kW. These include the Plug-flow digesters, Lagoon digesters, Up-flow sludge blanket digester and the complete mix digesters (SAIREC, 2015).

2.3 Mechanism for biogas production

Biogas is produced when any type of organic biodegradable material decomposes in the absence of oxygen, which is referred as anaerobic digestion process (AD). Biogas consists of methane (CH4), carbon dioxide (CO2), and (H2S) and other trace gases. Depending on feedstock sources, average composition is made of methane between 40% and 75%, carbon dioxide 25% and 40% and the remaining being other trace gases which include Hydrogen (5%-10%), Nitrogen (1%-2%), water vapour (0.3%), ammonia and traces of hydrogen sulphide (Salomon and Lora, 2009).

It takes 1–2 cows, 5–8 pigs, or four adult humans to supply adequate daily feedstocks for a single-household bio-digester and the daily input of dung and urine from a single cow produces

1–2 kilowatt of electricity per hour or 8–9 kilowatt of heat per hour. Furthermore, biogas installation of 10 m^3 can provide sufficient energy for cooking for two families of four persons. The production of energy is influenced by factors such as microbes, design of the plant, construction materials, climate, chemical and microbial characteristics of inputs, and the interrelationships among these factors (FAO, 1996).

The slurry left after anaerobic digestion is rich in ammonia and adds value to the process of agricultural as it can be used as fertiliser. Other important uses and benefits of anaerobic digestion include degasification of manure, the minimisation of sludge volume generated from wastewater treatment processes, and sanitation of organic waste from industrial deposition. Production of renewable energy, advanced waste handling method and a well-integrated bio-refining concepts are defined as the major market players for anaerobic digestion that will likely expand rapidly in the near future (Madsen *et al.,* 2011).

A combination of four basic processes are involved in anaerobic digestion; namely, hydrolysis, acidogenesis, acetogenesis and metha- nogenesis. Hydrolysis which is the first stage, is the stage where complex soluble polymericorganic matters such as proteins, fats and carbohydrates are enzymatically hydrolysed into simpler soluble organic materials like sugars, fatty acids and amino acids. In the second stage, acidogenesis, a further breakdown of the material occurs through fermentation by acidogenic bacteria to produce ammonia, carbon dioxide and hydrogen. Other low molecular weight organic compounds such as carbonic acids and alcohols are also produced [96]. Further digestion of these molecules in the acetogenesis stage produces mainly acetic acid, hydrogen and carbon dioxide. Methanogenesis is the final stage where the products of acetogenesis are converted by methanogenic Archaea into a mixture of methane and carbon dioxide, known as 'biogas' (Madsen *et al.,* 2011).

The fermentations process in the production of biogas are achieved in anaerobic digestion. Depending on the process condition selected, there are four different digester-configurations, which could be one of the following: Batch or continuous, Two-phase or two stage, Dry or wet fermentation and Mesophilic or thermophilic.

The batch system is the simplest form of anaerobic digestion. The substrate is added to the digester at one time and digester is sealed for the duration of the process. After digestion, the effluent is removed (Madsen *et al.,* 2011). In the continuous method, substrate are constantly or periodically added in the digester, while the end-products are constantly or periodically removed. In this method, it is ideal to have equal amount of slurry in as well as leaving the digester, thus special consideration should be specified to the design of the inlet and outlet for the slurry.

In the two-phase or two-stage process: The main aim behind the digestion is to separate the anaerobic food chain into microbiological processes which is hydrolytic/acidogenic phase (first phase) and acetogenic/methanogenic phase (second stage). The purpose is to provide optimal environment for each of the distinct microbial populations that are performing these biochemical transformations and hence allowing an overall faster reaction (Scarlat, 2015).

Dry or wet fermentation: normally, two main systems are used in the dry fermentation, which are the percolation and the bed system. In the percolation system, the input is stacked up in a gas tight container and left to ferment for a period of time while simultaneously spraying with optionally pre heated circulating water. In the bed system, it works essentially without water. Wet fermentation typically involves mixing the substrate with water before stacking up the fermentation tank. This process requires regular or even better continuous mixing in order to prevent the sinking or flotation of the solid materials. Accumulation of ammonia is a critical parameter in wet fermentation, as it inhibits the microbial process (Madsen *et al.,* 2011).

Mesophilic or thermophilic digestion: A digester can be classified as mesophilic or thermophilic, depending on the temperature employed and the species of methanogens involved in the digestion. Most mesophilic operations run within a temperature range from 20-45 ^{0}C. A thermophilic system requires the digester in an operating temperature typically in the ranges of 50-60 ^{0}C, which in turn requires more energy input to maintain the elevated temperature. Thus, the higher the temperature increase, the higher the rate of reaction, leading to fast breaking of organic matter by the thermophilies thereby increasing the rate of biogas production (Nekhubvi and Tinarwo, D. 2017).

2.4 Designs of Biogas Plants used in South Africa

There are several types and designs of biogas digesters worldwide. However, in South Africa, the designs developed in the last century have been often adopted. These designs can be broadly categorised into domestic/rural digesters and agricultural/industrial digesters. The domestic/rural digesters are mainly of simple designs and include the Chinese fixed dome, the Indian floating cover, DIY Biobag Digesters Kit, the Deenbandhu Model Digester, In-Situ concrete cast digester and Agama fixed dome.

2.4.1 Fixed-dome (Chinese design)

The fixed dome digester also referred as Chinses digester is about the most common type of digester. The size of the fixed dome digester varies due to the number of households, location and availability of substrate. It is buried underground to avoid temperature variation (Rajendran et al., 2012). The fixed dome digester consists of a shallow well with a dome rooftop. The inlet and outlet are above the ground with the gas pipe fitted on top of the dome. The digester is filled through the inlet pipe until the level reaches the bottom of the expansion chamber. The upper part of the digester is called the storage part accumulate the produced gas. The expansion of chamber creates a gas pressure due to the difference in the level between the slurry inside the digester. The collected gas requires space and presses a part of the substrate into the expansion chamber. Immediately, the slurry flows back into the digester as soon as the gas is released ((Rajendran et al., 2012).). Figure 2.1 shows a diagram of a typical fixed dome digester.

The digester exhibits some advantages; namely, is the construction materials that are readily available in the rural areas, making it affordable for the residents. It also has low maintenance costs and there are no metallic parts in the construction that could be prone to rust. There are, however, some disadvantages to the fixed dome, which include the supplies of gas at variable pressure as the gas dome is of constant volume and once the gas begins to be used, there is no means provided to maintain its flow at constant pressure. The implication of this is that the gas becomes less efficient in running biogas equipment, such as lights, water heaters, and generators. Furthermore, the construction materials is prone to cracking, thus, it requires a very skilled masons which often times not available in many cases and also consume time (Mutungwazi et al., 2018).

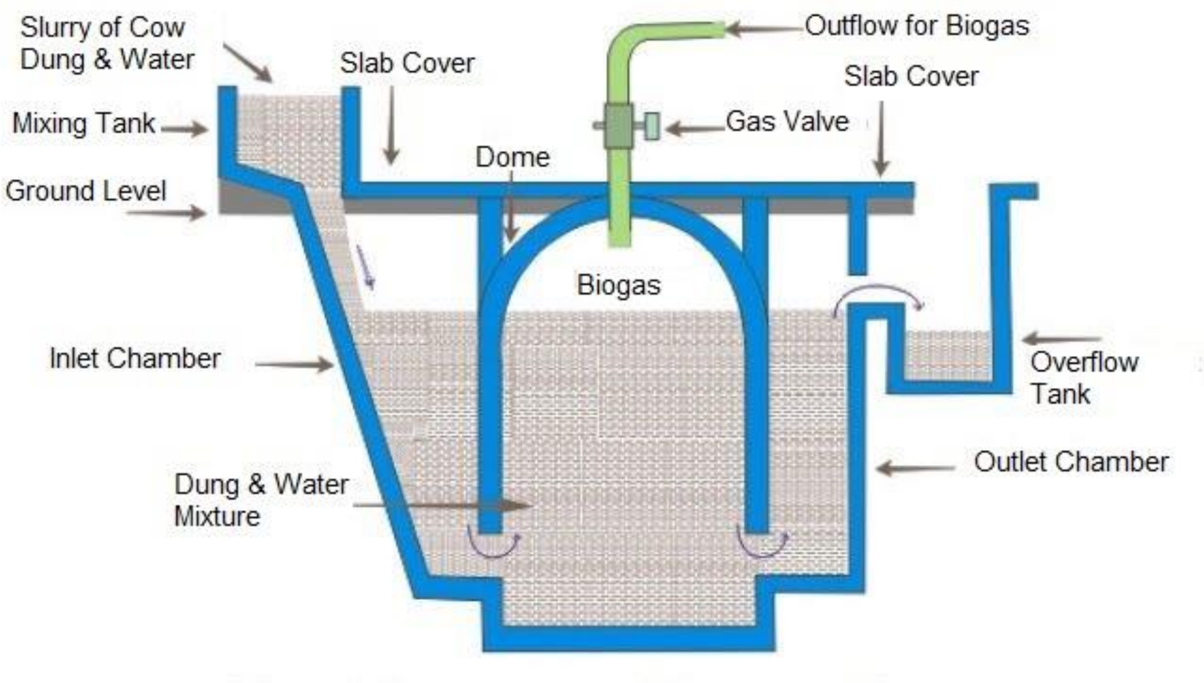


Figure 2.1: A Fixed dome digester.

2.4.2 Indian Floating Cover

The floating cover design is a well-shaped digester with a moveable inverted drum that is placed on top of the digester. The design, also include an inverted steel drum that acts as a storage tank which can move up and down depending on the amount of the gas produced. The weight of the inverted drum implies that pressure is needed for the gas to flow through the pipeline for use. The gas is produced at a constant pressure with variable volume and due to the position of the drum, the accumulated gas is easily detectable (Sing and Sooch, 2004). Figure 2.2 shows the floating cover biogas digester design.

There are several designs of the India digesters, such as the KVIC Model, Deebandhu Model and the Pragati Model. The KVIC model is a biogas plant with a floating with constant pressure of upward and downward movement of the gasholder. The Deenbandhu model, which is cheaper in cost compared to the KVIC, has two sphere segments of different diameters that are joined in the base. The Pragati model is a combination of the KVIC and Deenbandhu models and it is designed in a semi spherical shape in the lower part of the digester with a conical bottom where the gas are stored in the floating drum (Ghafoori and Flynn, 2007).

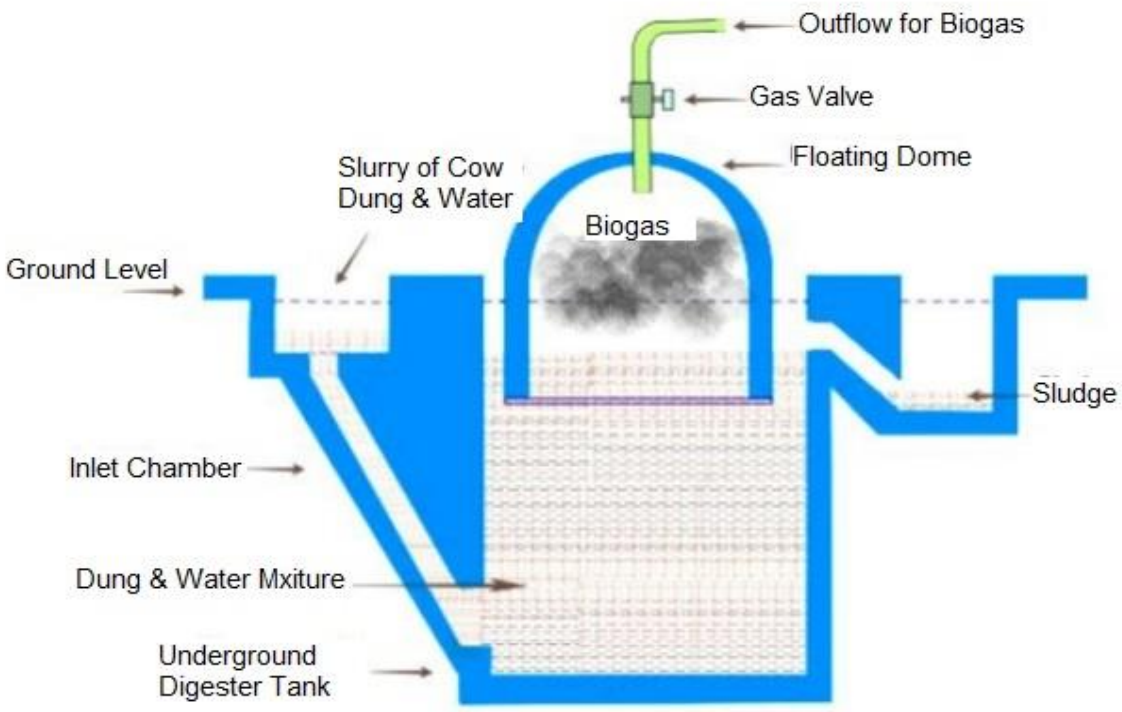


Figure 2.2: Indian floating drum biogas digester (Hamilton, 2014).

2.4.3 DIY Bio Bag Digesters Kit

The Do-It-Yourself digester is a Taiwanese model that is made of soft plastic bag, which is sealed in a tubular form. Figure 2.3 shows a tube digester. It comes in various sizes and thickness. In some developing countries, these are referred to as "tube digester, balloon digester, sausage-type digester and bladder digesters". In design, it consists of a long cylinder made from durable Polyvinyl Chloride (PVC), which is resistant to bacteria, with exceptionally strong flexible material of red plastic mud or polyethylene. The DIY bio-bag digesters were designed and developed to solve associated problems of bricks and mental digesters (Cheng *et al*., 2014). The installation requirement is simple, with limited training. This makes it ideal for households in rural areas. The digester has two waterproof inlet and outlet that ensures substrate flow under gravity. The rounded bottom shape helps in the flow of content and excavation from the inlet through the outlet.

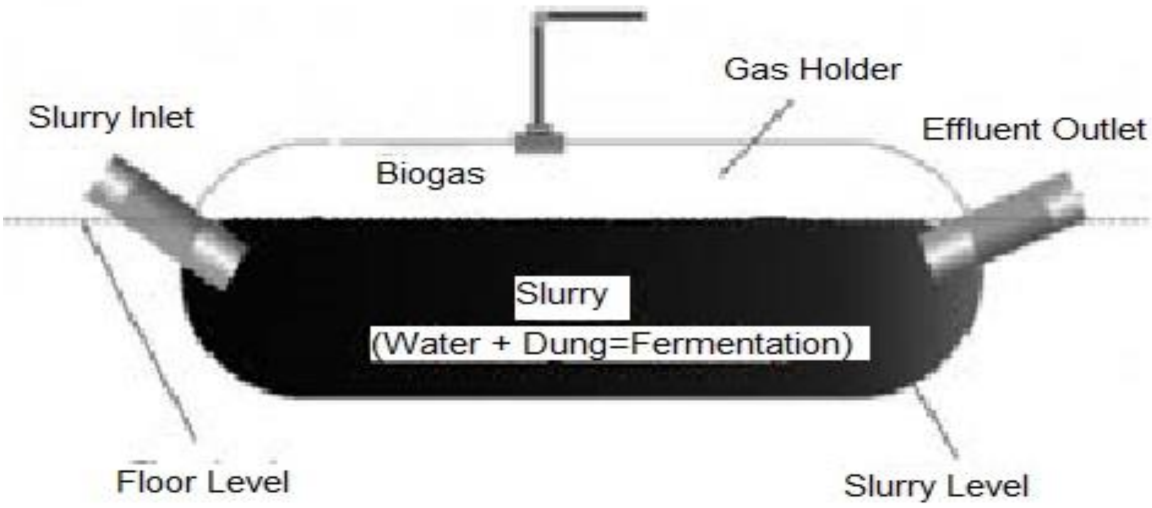


Figure 2.3: A Tube digester (Hamilton, 2014).

2.4.4 Deenbandhu Model Digester

The Deenbandhu is an improved design of the floating cover digester. The Deenbandhu (Figure 2.4), is typically used in rural villages of South Africa. The design is an improvement made to use less of construction materials and thus reduce cost. From the materials used, the structure is more crack-proof and reduces the surface area of the biogas plant. In the design, there are two spheres of different radii that are joined together at the bottom. At the base, the diameter curvatures of the digester helps in nullify the force from the ground, with a sphere-shaped structural power, which is more than those of the rectangular structures (Florentino, 2003).

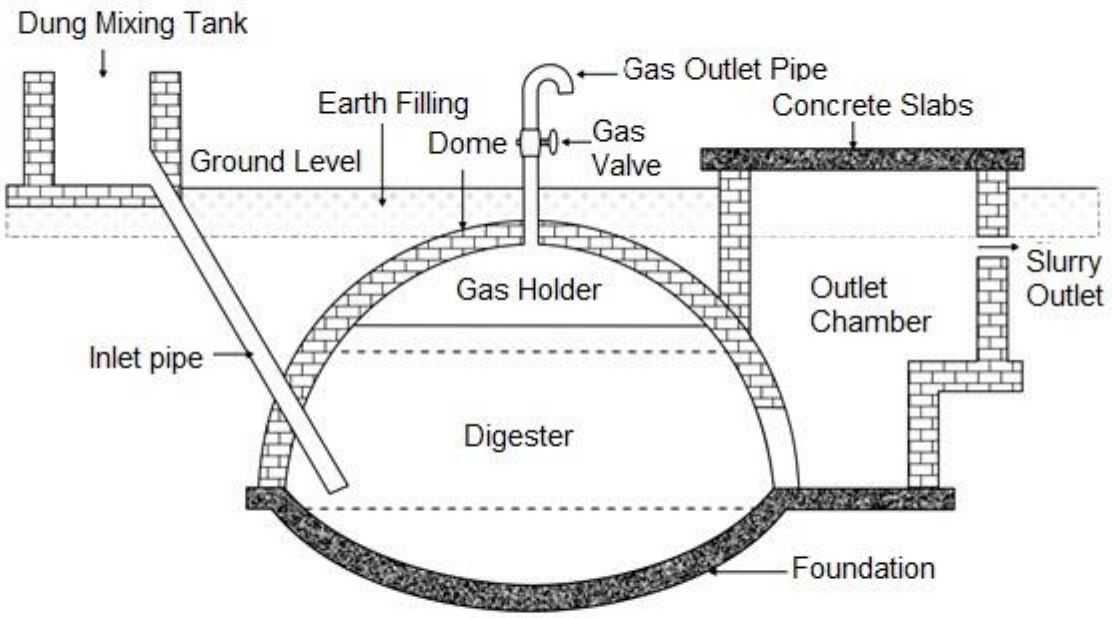


Figure 2.4: A Deenbandhu model digester (Hamilton, 2014).

2.4.5 In-situ concrete cast digester (Puxin)

The digester application is on a household scale for the treatment of food waste and sewages. The hydraulic design of the digester is centred to solve the associated technical problems and has enhanced its advantages over the floating drum and the fixed dome digesters. The construction of the digester consists of a shutter system with a bolted steel panel that is erected like an igloo around the digester where the concrete is cast. The shutter is dismantled when the concrete has gained enough strength and it can then be used again to form another digester. The digester consists of an inlet and outlet pits, plastic fibre gasholder, neck and belly. The digester functions as a hydraulic system when the digester is entirely flooded with water in the same level in the inlet, outlet and the digester neck (Cheng *et al.,* 2014) As the materials decompose under the water, the ideal anaerobic conditions are created for methane production. As the amount of the gas is produced increases, the water is displaced downwards and the gas rise upwards due to pressure of the opposite and equal reaction of the water that is displaced (Cheng *et al.,* 2014). It is easy to clean the digester and thus any type of organic material such as grasses, leaves, and straw can be used as feeder thus giving it the advantage of its application where animal waste is not available in the required quantities but enough organic materials are obtainable.

2.4.6 Agama fixed dome

BiogasPro in South Africa developed the digester design. The digester is made of a plastic roto moulded digester and uses the same operating system of the same style of the fixed dome. Typically, the digester volume is 6 m^3, fed with about 40 kg of organic waste per day, with the capacity of producing 2 m^3 of biogas per day. This equals 3.5 kWh of electrical output and can suffices 4 hours burning time. The digester version is greatly modernised with the advantage of being anticorrosive and leak proof because it is made of plastic (Cheng *et al.,* 2014). The Agama fixed dome has the advantage of its designed to being able to handle human waste which is rich in nitrogen; hence working well in increasingly adjusting the carbon/nitrogen (C/N) ratio (Ghosh and Bhattacherjee, 2013). The limitations of this design is the tendency of solids to remain at the base, thereby requiring constant clean up maintenance of the digester. Secondly, the supply of gas is at variable pressure. The digester is ideal for eco-lodges, farmers, rural schools and “green” households

2.5 Decision Analysis for Technology Adoption

The technological innovation can gain acceptance if it is appropriate and the innovation needs to be adopted by the intended users if it is to produce the anticipated impacts. The process of adopting remains a concept of multidimensional intrigue because there is no specific mode by which the process of adoption proceeds. Hence some new technologies are quickly adopted while other lag behind (Cramb, 2003).

The perceptions of adoption suggests that, people reflect on many characteristics in choosing a certain technology and the reason involves necessitating investigation of a large number of tangible and intangible characteristics of the technology. In a choice support environment, it is asserted that consumers have subjective preference generally for attributes of products and their demand for a certain product is subjectively affected by their perceptions of the product (Chan *et al.,* 2000). According to Sinja *et al.,* (2040), users interface directly with the technology and their sensitivity of the technology are attributes that have a major effect on the rate of adoption and often users will discard certain technology not suitable and which may interfere with other activities considered more important in their environment. Thus, the adoption of a technology depends on many factors which make prospective users adopts or reject a technology, and these factors include, the absence of involvement of the user, lack of understanding, inefficient and insufficient support, technical difficulties and perceived complexity in the technology. The adoption rates incorporate the incidence, which is the percentage of people using the specific technology at a precise place in time, the intensity of adoption involves the levels at which it has been adopted and the rate is the proportion of people, over time who have adopted the technology (Senkondo *et al.,* 1999).

2.5.1 Theory of Reasoned Action

The Theory of Reasoned Action was first developed in 1975 by Fishbein and Azjen and was applied in the field of sociology and physiological research. Recently, it has been used to investigate individual behaviour toward technology adoption (Kuo *et al.,* 2015). Figure 2.5 shows the theory of reasoned action. According to the model, any behaviour of human is predicted and explained through three component cognitive which are: attitude (favourable and unfavourable of a person sentiment of a behaviour), social norms (social influence), and intentions (a person's decision to or not to). The model emphases that human behaviour should be systematic, volitional and rational. The three factors boundaries; namely, control of volition, stability of intention over time, and intention measurement in relation to context, action, target and specificity, are tests that are defined to evaluate the theory of reasoned action. Additionally, methods such as target, context, action, time horizon and generality are created in improving the heftiness between attitude and matching intention (Kuo *et al.,* 2015). The theory is deficient because it is inadequate in addressing the role of habit, deliberation cognitive, survey misunderstanding through subjective norms, respondents' intention, attitudes and other moral factors. Moreover, a crucial issue of validation is based on usage voluntariness.

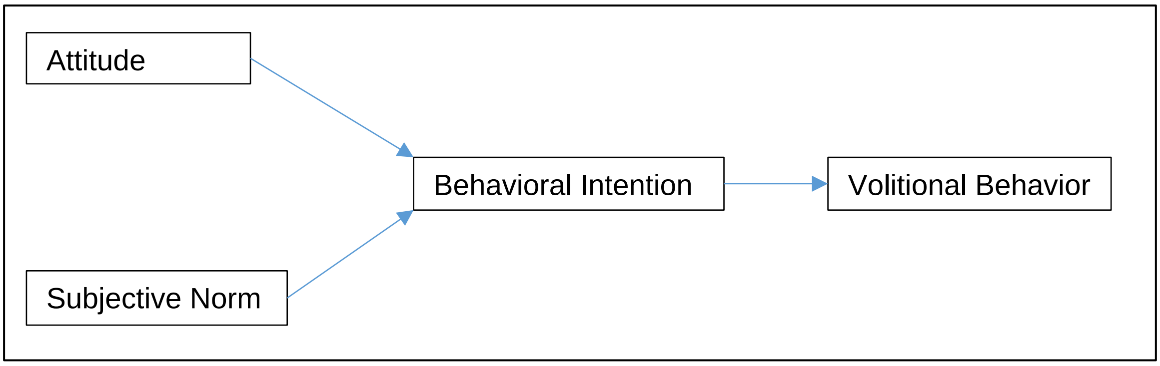


Figure 2.5: Theory of Reason Action (Source: Kuo *et al.,* 2015).

2.5.2 Diffusion of Innovation Theory

The theory was propounded by Everest Rogers. It seeks to explain how, why and the rate at which new technology and ideas are spread. Figure 2.6 shows the illustration of the diffusion of innovation theory. The theory is considered as one of the most appropriate in investigating technology adoption and has been used globally at individual and organisational level as theoretical foundation. The argument is based on the process at which an innovation is communicated to participants on a social system over time. A social system, time, communication channels and innovation are the four key areas. Adoption according to the theory is a decision of “full use of an innovation as best course of available action” and rejection decision “not to adopt an innovation”. Three major components incorporated in the theory are the characteristics of the adopter, innovation characteristics and decision process of the innovation. Five steps, knowledge, decision, implementation, persuasion and confirmation are critical in the innovation decision, which over time passes through a chain of communication channels among members of a social system. These channels are similar. The five main constructs considered as operative factors for acceptance in the characteristics of an innovation are its relative advantage, complexity, triability, observability and compatibility. Early majority, early adopters, laggards, late majority and laggards are the five categories in the adopter characteristics (Sila, 2015). The diffusion of innovation focuses more on system characteristics, environmental aspects and organisational attributes, making it less powerful in practical prediction and explanatory of outcomes as compared with other adoption models.

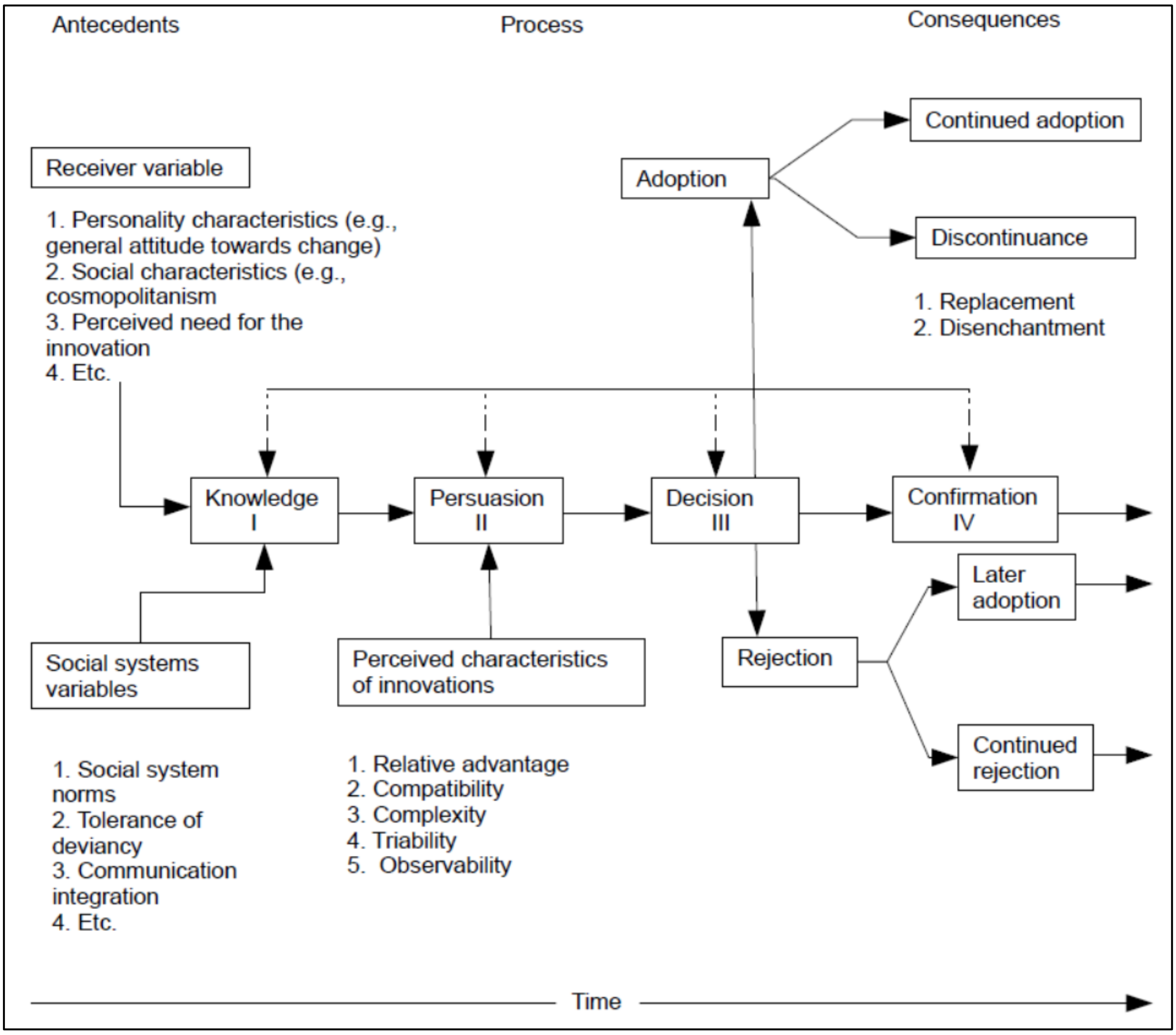


Figure 2.6: Diffusion of Innovation model (Source: Roger, 2003).

2.5.3 Technology Acceptance Model

The technology Acceptance Model was introduced by Davis in conceptualising technology acceptance. The TAM is a derived from the Theory of Reasoned Action (TRA) due to uncertainity in the psychrometic and theoritical status. Figure 2.7 shows the technology acceptance model. The Technology Acceptance Model postulates that the motivation of users of a given technology are centered on the dynamics of behaviouriaal intention of the user and atitutde towards the technology and two internal factors which are perceived usefulness and percieved ease of use. Davis defined the perceived usefulness as the potential user subjective probability that using a specific technology will increase the consumer satisfaction and the perceived ease of use as the extent to which the potential user expects the technology to be free of effort (Davies, 1989).

According to the model, behavioural intention defines the actual use of a given technological system and consequently determines the technology acceptance. Attitude towards use and perceived usefulness together influences the behavioural intention. Indirectly, behavioural intention is affected by the perceived ease of use while attitude towards use is directly influenced by both perceived ease of use and perceived usefulness. In turn perceived ease of use is directly influenced by perceived usefulness. Further, the technology acceptance model conceived that perceived ease of use and perceived usefulness are determined by external variables. Therefore, there is a mediation between perceived ease of use and perceived usefulness, which results in the external variables influence of the users' attitude and behavioural intention; therefore the actual technology usage (Davies, 1989).

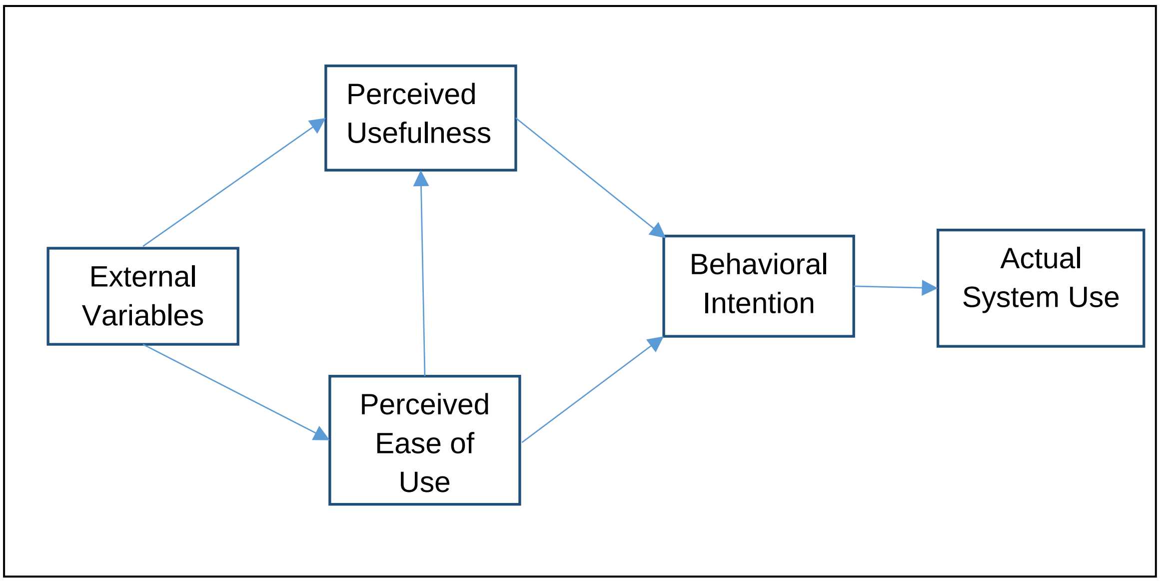


Figure 2.7: Technology Acceptance Model (Davis, 1989).

2.5.4 United Theory of Acceptance and Use of Technology

In the late 1980s, several models for the acceptance of technology were developed and tested. In 2003, Venkatesh *et al.* developed the Unified Theory of Acceptance and Use of Technology (UTAUT). Figure 2.8 shows the illustration of the unified theory of acceptance and use of technology model. The model was premised on performance expectancy, effort expectancy and social influence have a positive effect of user behavioural intention. Argued in the model is that prediction of behavioural intention is a subject to moderated effects from age, experience, gender and voluntariness of use. Behavioural intention and facilitating conditions have a positive effect on the behaviour of a user (Venkatesh *et al.,* 2003).

Performance Expectancy in the model replaces the perceived usefulness construct in the technology acceptance model. Performance expectancy is defined as the extent to which an individual trusts the technology would be beneficial. Effort Expectancy is considered as the ease of the technology. It is based on the perceived ease of use from the technology acceptance model. Social influence in the model is defined as the point at which individual or user perceives the importance of others (friends and family) in considering the use of new technology. Under social influence, the assumption is that friends and family will positively influence a user on the adoption of a technology. The facilitating conditions are the extent technical system is readily available and capable to support the use of a technology (Venkatesh *et al.,* 2003).

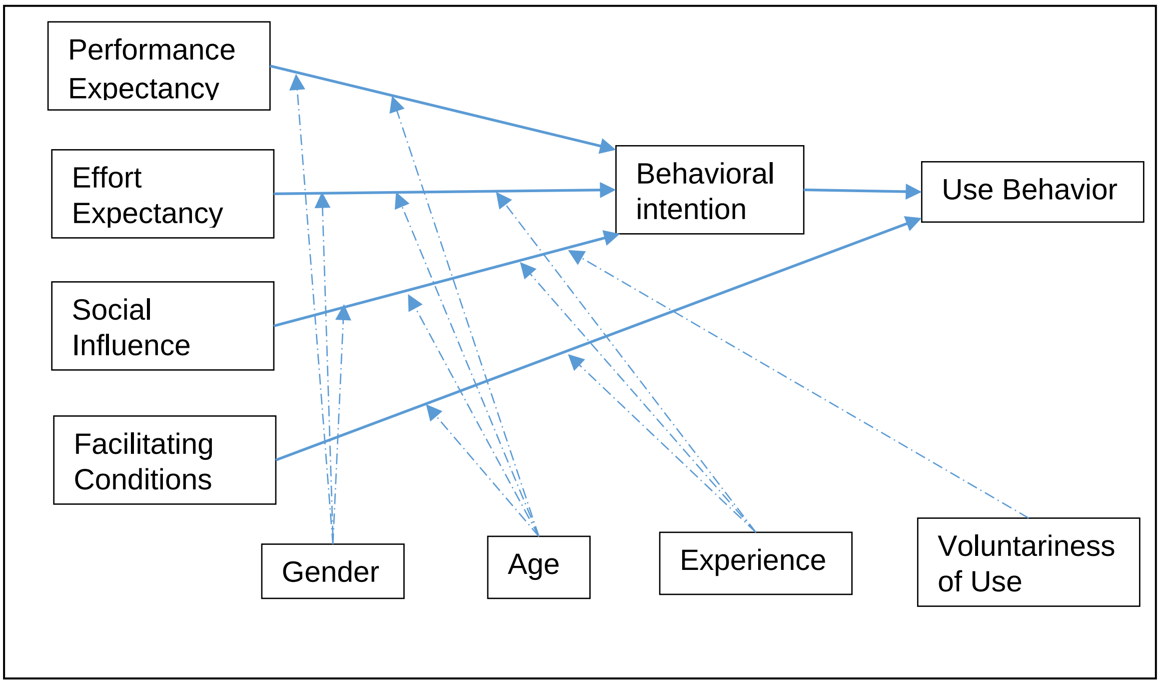


Figure 2.8: Unified Theory of Acceptance and Use of Technology (Venkatesh *et al.,* 2003).

2.6 Factors Influencing the Adoption of Innovation

The adoption of innovation depends on various factors. These factors may differ across regions and sometimes are location-specific. Several studies have pointed out that adoption and dissemination of new technologies depend largely on demographic characteristics, environmental characteristics, institutional support services, the nature of the technology and its benefits as perceived by the clientele. Such characteristics make adoption responses unique, as they are related to the individual, some to the situation in which the individual is and some to the nature of the practice. In addition, some innovations are also subject to the control and manipulation of change agents, while some are not specific to the study area and often incomparable.

Despite the several advantages and numerous demonstrated experiences of biogas technology as a source for renewable energy and strategy for good waste management, biogas technology has not been fully embraced in South Africa (Okudoh *et al.,* 2014). This is due to a number of factors. Income levels of households are not the only considered factor in investing in biogas technology. Operating from national level of the economy to the individual households are socio-economic, Institutional, technological, geographical and environmental factors, which play a paramount role and influence in the decisions of households to invest in biogas technology (Inayatullah and Waqar, 2018). Decision by households to adopt and utilise biogas technology are influenced by crucial factors operating at national level, by providing conducive environment and incentives that could attract households in investing in biogas technology (Inayatullah and Waqar, 2018).

2.6.1 Socio-Economic Characteristics

Socio-economic characteristics are associated factors that contribute to adopting or rejecting a technology. These factors include age, education, gender, household size and income. The age of the household head can negatively or positively influence the decision whether to adopt biogas technology or not. According to Nhembo (2003), conservatism is associated with old age and may influence a person's willingness to or not adopt new technologies. Older people may not be ready to experiment with new technologies and ideas because they are deemed to be more risk averse. Sometimes, however, old people are considered as having extra resources, with higher economic status that will permit them to engage in capital-intensive technologies than younger people. On the other hand, younger head of households are considered to have long planning horizons and therefore are more innovative and believed to take risks associated with new technologies. There are thus some new technology and innovation where younger heads of households stand a better chance of adopting than older heads of households.

Better creativity capacities for greater access to information are often associated with the educational level a person has attained. Therefore, and educated household head is considered more aware of new technology; better informed and environmentally conscious about the adverse consequence on the environment because of fossil fuel consumption (Kabir *et al.,* 2013; Inayatullah and Waqar, 2018). Based on environmental awareness, it is assumed positively that individuals that are more educated will go for a cleaner energy source, such as biogas, as compared to less-educated counterparts (Kabir *et al.,* 2013; Inayatullah and Waqar, 2018). Thus, uncertainty is reduced by educational knowledge and therefore chances of adoption are enhanced. The gender of the household head can positively or negatively motivate the adoption of biogas technology, depending on the gender tasks. The gender duties could be in the form of performed tasks between women and men in energy supply. According to Karekezi (2002), in most rural households, women control domestic supply of energy, as it is considered their primary responsibility, such as fuelwood collection, waste disposal management, food preparation, and home maintenance.

Household size is also a factor anticipated to positively or negatively influence household decision on technology adoption, such as biogas. Oftentimes, a large family means having more assistance for the routine maintenance and operation of a technology, such as biogas. A larger family, therefore, is considered as having greater chances of adopting biogas technology. On the other hand, a bigger household could mean exerting a heavy dependence burden on the family's scarce means to the level that there could barely be any reserves left to invest in a technology such as biogas. In situations like these, household size could negatively influence decisions regarding biogas technology. According to the findings by Kebede *et al*., (1990) if family relations are seen as additional sources of assistance, then the farmer may try new practices. However, if they are regarded as dependents, then the reverse may apply. The uptake of technology is driven by income earned by households. Thus, middle-income levels are anticipated increase the chance of adopting biogas technology compared to households with lower income levels. Therefore, household income is projected to carry a positive symbol as it is hypothesised that the adoption of biogas technology increases with household income levels.

In Kenya for example, Mwirigi *et al.,* (2009), studied the socio-economic obstacles for the adoption of biogas technology and its sustainability impacts. The conclusion drawn was that the status of the farmers' socio-economic standing meaningfully determines their decisions to adopt biogas technology but not the sustainability of the biogas digesters already installed. In the studies on the sizes of household digesters in Uganda, it concluded that household size, numbers of cattle owned, cost of traditional biomass fuels and household income were the factors influencing the technology adoption (Walekhwa *et al.,* 2009). In China, the factors influencing farmers' decision in adopting the technology were Government support and related household factors, such as income level, household size and age of household head. For Bangladesh, the determining factors that influenced the technology adoption include the gender of the head of household, educational level, number of cattle owned and income level (Kabir *et al.,* 2013). The findings in Pakistan by Inayatullah and Waqar (2018) unravel the factors influencing biogas technology to include the level of education, daily electricity shortfall and its effect on children's education, female drudgery and awareness of the technology. Further, the study findings in Pakistan included socio-economic status as well as awareness about the technology (Abbas *et al.,* 2017). Amigun and von Blottnitz 2010, Mukumba *et al.,* 2016, studied cost analysis as a factor in biogas technology adoption.

2.6.2 Institutional Characteristics

Institutional support is another factor affecting adoption of a technology. Rejection or acceptance of a new idea depends largely on how the information is relayed from the source, which is mainly the extension service. Extension services are known to catalyse awareness, organisation, and information exchange and technology promotion among individuals.

Information dissemination is a key process in bringing awareness about the presence of a new technology. After being aware of a new innovation, people would accumulate knowledge and then test the innovation and adoption is expected to happen after people become satisfied with the results of the test. Abadi-Ghadim and Pannell (1999), point out that adoption is a multistage decision process involving information acquisition and learning by doing. Consequently, information is one of the crucial software aspects of innovation and information, acquired during any given period is, in part, a decision variable (Burton *et al.,* 1999). People with more access to information are expected to benefit much from the technology introduced in their areas. The accumulation of information over time is hypothesised as one of the main dynamic elements of the innovation adoption process because it raises the level of knowledge.

If the innovation is profitable, the accumulation of favourable experiences will eventually induce the individual attitude towards adoption of a new innovation (Anin, 1999). Extension education provides access to information and makes a substantial contribution to motivating adoption or influencing an increase in the intensity of use of the technology (Baidu-Forson, 1999). It can therefore be concluded that before adopting any innovation a certain level of cumulative information must be attained while on the other hand, information problems may limit people's ability to anticipate correctly the long-term profitability of a given technology. Other factors like availability of credit facilities, market, policy and other institutions are also important in encouraging adoption.

2.6.3 Technological Characteristics

Technological characteristics are also factors influencing the adoption of a technology. Rogers (2003) identified five major technological characteristics associated with high rate of adoption of technologies. These include the relative perceived advantage, compatibility with the local culture, low technical complexity, traiability and affordability. Prior to adoption, people do their analysis and finally adopt technologies with characteristics of their preference. Another technology specific characteristic is the performance of a technology under individuals' conditions. Poor performance of a technology can discourage people from adopting it.

Bartz *et al.,* (1999), observed that technologies with short-term benefits are more preferred than those perceived to have long-term benefits since long periods required for realisation of the benefits of the technology, which make them more uncertain and less attractive. Governmental support to such technologies is more crucial, where the support can be in the form of subsidies, loans and provision of technical services, to encourage people to adopt the technologies.

2.6.4 Geographical and Environmental Characteristics

Geographical characteristics, such as location, also play a part in the adoption of a technology. The energy required is produced mainly from raw materials that are locally available, making it a cheaper and simpler option. In adopting the technology, the adopters can either be urban or rural dwellers. However, the low adoption rate of the technology in remote areas could have been orchestrated by their close and easy access to the natural forests where they can harvest fuelwood almost at will.

2.6.5. Biogas Technology Dissemination

Developing countries are intensively promoting the dissemination of biogas technology. These countries have launched several dissemination programmes with some or all of the following components: development of appropriate appliances and plants establishment of technology, advisory-service centres, continuous support for the users and training of practitioners. Other components include advertising and promotional activities, assistance for private artisans and provision of financing assistance. Werner *et al.,* (1989) asserts that adoption of biogas in the developing world is highly dependent on political, economic, logistical and social factors and a key to successful adoption appears to be direct observation and experience.

The development of biogas technology depends on the political will of donor and recipient governments and it is the task of the government and administrative authorities to provide access to the technology and to secure and organize the requisite material, financial and legal basis. Governments can play a more or less supportive role in research, information dissemination and regulations for funding, subsidies or tax waiving. Ghimire (2008) indicates that government offices in the villages, provinces and districts have a role to play in coordinating the activities and integrating related biogas activities to their daily routine, while local government bodies have to engage in information dissemination, motivating potential users and bridging the users and the projects.

Among the roles of biogas programme offices is to implement the activities, as stipulated in the guidelines, engage in capacity building, quality control of construction and after sale services, updating of database of completed plants, and in promotion and extension services. Werner *et al., (*1989) further comment that political will and public opinion develop in interrelation successful practical examples, encouraging research funding, the use of media to spread information, all these are tools to influence the adoption of the technology.

Apart from government institutions, other stakeholders in the dissemination of biogas technology include Non-Governmental Organisations (NGOs), Community-Based Organisations (CBOs) and functional clubs or groups working at grassroots levels. Their roles are to promote the technology, by motivating farmers through disseminating factual information on technology benefits, organising community level workshops and seminars and conducting users training, capacity building, to facilitate operations and maintenance activities and be instrumental in penetrating rural needs communities. The existing and or potential users are also the key stakeholders of the technology. Satisfied users are very good motivators and disseminators of the technology through sharing of their views to potential users. Their decision to invest in biogas installation and carrying out operations and maintenance activities provide opportunities of demonstrations to other potential users (Ghimire 2008).

Furthermore, since the impacts and aspects of technology concern different governmental and non-governmental institutions, it is necessary to identify and include all responsible departments in the dissemination and awareness-raising process. Without public awareness of the technology, its benefits and pitfalls, there will not be sufficient basis to disseminate biogas technology at grassroots level. Inadequate expertise in the construction and maintenance of biogas digesters is also a major challenge impeding the dissemination of biogas technology. There are hardly vocational or technical colleges or schools that teach people how to build and maintain biogas digesters. A number of failed biogas related projects are partially due to inability to properly manage the digesters. More so, another technical issue related to the dissemination of the technology is that most of the digesters designed as pilot projects were built long ago and no longer operational (Mukumba *et al*., 2016).

2.6.6 Government Institutions Involvement in Biogas Technology Promotion

The South Africa government's involvement in renewable energy can be traced to the country constitution. Government policies has created the foundation and was ranked in 2014 as the 10^{th} top investor in renewable energy by the United Nations. The first document was the 1998 White Paper on Energy Policy. The National Energy Act (Act No. 34 of 2008), aims to ''strengthen energy planning in order to ensure that diverse energy resources are available in sustainable quantities and at affordable prices to the South Africa economy and more, specially to provide energy planning, increased generation and consumption of renewable energies''. The elements in the act are strategies in developing domestic energy resources that are considered to be cheap, promote the economy, reliable, secured and efficient (DoE, 2015).

In South Africa, biogas is the only exceptionally recognised form of renewable energy, which contributes to the sustainable management of waste, converting agricultural and other organic waste into energy, thus reducing emissions of carbon from waste decomposition and conventionally displacing energy supply. This is relevant on large commercial scale for organic waste streams and on small scale application for both commercial and domestic biogas digesters that process waste to produce methane as energy, which is commonly increasing worldwide. However, in South Africa, only a handful have been developed to date (DoE, 2015).

The Southern African Biogas Industry Association (SABIA) estimated that 2.5 GW capacity could be attributed to biogas generation in the country from wastewater treatment plants, manure, food waste, residues from agriculture, as well as commercial processing from abattoirs, cheese factories and breweries. In addition, biogas technology is the only renewable energy option that is included under the ministerial determination for which no Independent Power Producers have been received until date. In the rural areas of South Africa, where there is unreliable electricity supply from the national grid, small scales biogas, digesters are encouraged and in terms of the National Legislation 102. Owners of biogas plants that are not connected to the national pipeline gas grid, do not have to be licensed but are required to be registered with the National Energy Regulator of South Africa (NERSA), (DoE, 2015).

2.7 The nature and significance of rural energy use

Tropical Africa depends largely on fuelwood for nearly 90% of its domestic energy supply. This is because fuelwood remain cheaper than most alternative energy forms available. For instance, due to the constant price increases of 1970, charcoal did not show any increment in its price trend and even if the price of fuelwood were to increase, the demand would have not decrease drastically, due to substitute unavailability (Boahene, 2008). Additionally, the extent of fuelwood use as alternative energy source, and its rate of consumption are influenced by a number of factors. These include, demand, cultural phenomenon, household sizes and environmental conditions (Kituyi *et al.,* 2001).

In developing countries, there are many faces of poverty and one such is coping with the limited means and lack of efficient energy technologies in households. In most Sub-Sahara African communities, poverty could mean among other things, having to rely primarily on dung and or wood for cooking and heating purposes. For these rural communities, in order for them to meet their household energy needs and demands through fuelwood, large areas of land are cleared along with its vegetation, thus, creating degradation and deforestation resulting in devastating environmental consequences. Estimates have revealed that every year, Africa is experiencing a net of nearly five million hectares of tropical forested land (Awino, 1999).

Therefore, Sub-Sahara Africa thrives on a very fragile environment that is threatened by deforestation, soil erosion and biodiversity loss, among other environmental concerns. According to Masekoameng *et al.,* (2005), as in many developing countries, in South Africa, rural areas are less privileged in terms of infrastructure and social amenities compared to urban areas. Where there are available services in these rural areas, they are customarily of low quality and limited in standards. With a large population living in these areas, even the energy consumed in these rural areas is mainly from traditional sources, such as cow dung and fuelwood.

A study conducted by Broadhead *et al.,* (2001) for Food and Agricultural organisation (FAO) revealed that developing countries, Africa in particular, are highly dependent on fuelwood as a major source of energy. Although other regions of the world show a steady decline in fuelwood consumption, while the demand in Africa is projected to increase tremendously until about 2030. Figure 2.9 shows the global projection trend in fuelwood consumption.

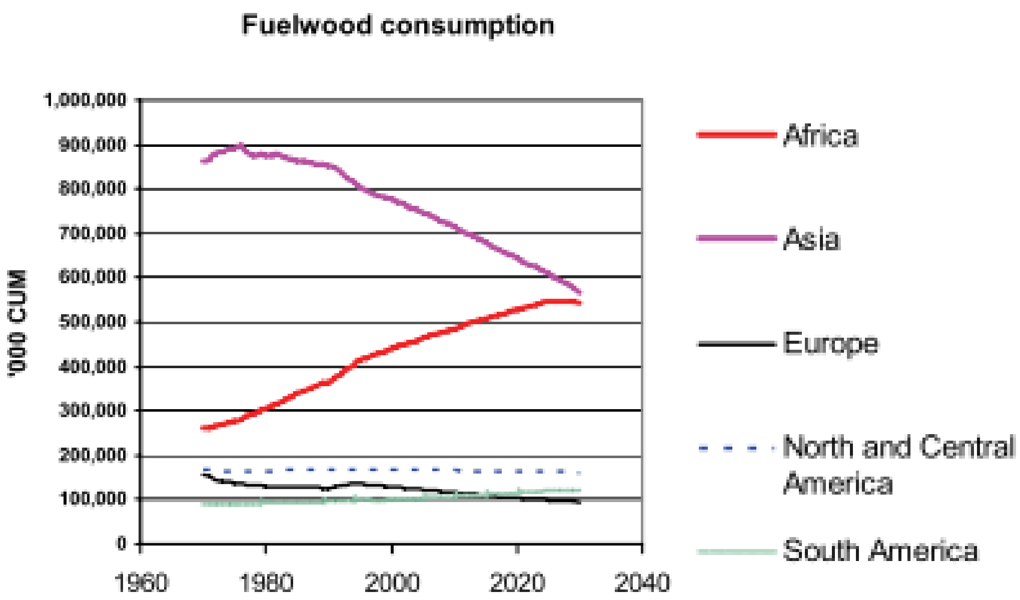


Figure 2.9: Past trend and future prospect of global utilisation of fuelwood for energy 1960-2040 (Broadhead *et al.,* 2001).

According to the best available figures, the use of energy in households in developing countries totalled 1 090 Mtoe in 2010, representing almost 10% of world primary energy demand. Biomass use in the households of developing countries alone accounts for almost 7% of world primary energy demand (IEA, 2017). Essentially, variations exist in the levels, types and consumption of fuels used as energy and the actual breakdown is difficult to obtain. However, in developing countries' households, energy is used mainly for cooking, followed by heating. In many countries, due to the climate and geographical conditions, household space and water heating needs are usually very small. Generally, households use a combination of energy sources for cooking, which can be categorised as traditional (fuelwood, dung and agricultural residue), intermediate (Paraffin/kerosene and charcoal) and modern (Liquefied Petroleum Gas and electricity). Generally, electricity is used for lighting and small appliances, rather than for cooking (IEA, 2017).

Even though in many developing countries, there is abundant biomass supply but local scarcity still exists. In addition, in some households, biomass is the only affordable source of energy. Thus, the commercial production and distribution of fuelwood and charcoal significantly generates employment and income for some rural households in developing countries. However, a switch to alternative fuels will also create business opportunities and employments (FAO, 2004).

In some Organisation for Economic Co-operation and development (OECD) countries and in most countries in economic transition, there are technologies available for converting biomass to energy which tends to be very efficient. The resources used are generally harvested in a sustainable way. On the other hand, in developing countries, the technologies and practices are poor and far less efficient. Thus, many households use three-stone fires, cook without ventilation or harvest trees in an unsustainable manner. The dependence on biomass resources are important to several communities. However, it cannot be viewed as sustainable when their use impair health and create negative environmental and economic impacts (OECD, 2006).

A compilation using a survey, census data and direct correspondence with national administration in developing region for each country indicated that the number of people that rely on biomass as their main fuel for cooking. It is estimated that over 2.5 billion people or 52% of the population in these developing countries depends on biomass for cooking. Over half of these people lives Indonesia, India and China. Yet, the proportion of the population that rely on biomass is highest in Sub-Sahara Africa (WHO, 2006).

In several Sub-Sahara Africa rural communities, more than 90% rely on fuelwood and charcoal as main energy source for cooking. In Latin America and Asia, poor households are also dependent on fuelwood as their energy source for cooking (FAO, 2004). The dependence on biomass is concentrated in, but not restricted to rural areas alone. Nearly half a billion people in urban centres also rely on this resources. Although, urbanisation is associated with lower fuelwood consumption, the use of LPG on towns and cities is not always evenly spread (Jannuzzi and Sanga, 2004). In urban centres of Sub-Sahara Africa, more than half of the households rely on fuelwood, wood waste or charcoal to supplement their cooking needs as over a third of the households in urban Asia also rely on these fuels (FAO, 2004).

In households, the share of biomass widely varies across regions and countries; hence, reflecting primarily not only their endowments of resources but also their economic level of development urbanisation. For example in Thailand where average per-capita income stands at $2 490; biomass account for 33%, while the share is nearly 95% in Tanzania (World Bank, 2006). Furthermore, there are important differences between urban and rural households. For instance, fuelwood for cooking purpose is three times more important in rural areas than in urban areas in both Botswana and India (Census of Botswana 2001 and Census of India 2001).

Clearly, households do not substitute one fuel for another even if their income increases but rather add another fuel in the process known as “fuel stacking”. Modern energy forms are usually applied economically at first and for particular services (for example, electricity for refrigeration, television and radio or LPG for making coffee or tea) rather than taking the place of an existing energy form that adequately supplies a service. Commonly, the most consuming activities in the house which are often cooking and heating are usually the last to be switched into the modern energy. Generally, using multiple sources of fuel in the household provides a sense of energy security, since the total dependence on a single fuel or technology leaves the household vulnerable to unreliable service and price fluctuation (Jannuzzi and Sanga, 2004).

Some reluctance to discontinue cooking with fuelwood may also be attributed to taste preferences and familiarity of cooking with traditional technologies. In India and many other countries, many wealthy households still retain a woodstove for baking traditional bread (Rwelamire, 1999). However, as income increases, fuel option begins to widen up. Thus, the fuel mix may change but fuelwood is rarely excluded as energy source.

2.8 Energy, Atmospheric Emissions and the Environment

The bulk of global energy supplies comes from carbon-based fuels, whose emissions threaten the environment, human health, climate and earths very existence (UNEP, 2012). Energy-related emissions are the core drivers of anthropogenic climate modification, aggravating patterns of environmental degradation and global warming with three major greenhouse gases namely; carbon dioxide, methane and nitrous oxide being responsible. Global emission of carbon dioxide (CO_2) has increased more than 46% since the late 1990s (UNDP, 2013). Precisely, emissions from fossil fuel burning are reported to have reached record high of 31.6 gigatonnes (Gt) in 2011, and in 2035 global greenhouse gases emission are projected to increase to an annual 37 giggatonnes (IEA, 2014).

Generally, it is presumed that biomass fuels are renewable and greenhouse gases free, because during combustion the carbon released in the form of carbon dioxide is taken up by the re-growing vegetation. However, the burning of fuelwood could result in the net emission of carbon dioxide, by decreasing the forest area and standing stock of carbon in forests (Subedi *et al.,* 2014). Fuelwood contributes to greenhouse gas emission through unstainable harvest and in the process of incomplete combustion. In addition, the burning of fuelwood gives rise to emissions of GHGs because dry wood contains about 50% carbon. Although, in a growing tree, the carbon content is much lower because dry wood contains a higher proportion of carbon. When one metric ton of dry wood are burnt 1.833 metric tons (1833 kg) of carbon dioxide is emitted (Lamlom and Savidge, 2003).

The emissions of GHGs has been identified by the Intergovernmental Panel on Climate Change (IPCC) as the key causes of climate change and the changes are regarded as any climatic change over time owned to natural variability and or human activity. From human-induced (anthropogenic) greenhouse gases, carbon dioxide, methane and nitrous oxide account for 92% of the total emission (World Bank, 2006). Generally, in Africa, carbon dioxide emission have increased in twelve-fold, reaching 311 million metric tons in 2008 which is still lesser than that of some single country like China, Japan, Russia, India and United States of America. In Africa, from all sources of fuels over time, emission has grown in all regions of the continent at approximately 35% (Boden *et al.,* 2011).

In Africa, however, small number of countries are mainly responsible for the emissions of fossil fuel. South Africa alone accounts for 38% of the total emissions, with the combination of Nigeria, Libya, Egypt, Morocco and Algeria accounting for 46% from the continent. On the continent, these six countries have annual carbon dioxide emissions in excess of 10 million metric tons. Four countries from the continent have a per capita carbon dioxide emissions higher than the global average of 1.3 metric tons per year. They are Libya with 2.53, South Africa 2.9, Seychelles 2.22, and Equatorial Guinea with 1.99 (Boden *et al.,* 2011).

Without policy actions, the rate of emissions is expected to increase and this will veer weather patterns and temperature that civilisation has adapted to and even further away from the norm. The promotion of renewable energy can assertively reduce carbon emissions owning the potential to save equivalent of 220 to 560 gigatonnes of carbon dioxide between 2010 and 2050 (IPCC, 2011). Greenhouse gases can be measured by recording the emission at source or by estimating the amount of emitted gases – multiplication of activity data (amount of fuel used) with the relevant emission factors. In cooking systems for example, the emission factors forms the basis of estimating the emission and the conversion factors allows activity data (tons of fuel or litres used) to be converted into kilograms of carbon dioxide equivalent (CO_2). The carbon dioxide equivalent is a universal unit of measurement that allows the global warming potential of different greenhouse gases to be compared (IPCC, 2011).

Increases in the concentration of carbon dioxide and other greenhouses gases in the stratosphere lead to global warming and eventually climate change. This change leads to adverses effect on ecological productivity, water reserves, biodiversity and human health of the socio-economic groups that has low adaptive capacity, which are especially the poor in developing countries. Climate change can exacerbate poverty and undermine sustainable development (IPCC, 2011).

According to Stern (2006), in order to reduce the harmful consequences of climate change, there is need to stabilise the concentration of greenhouse gases below 550 ppm of CO_2eq. The review argues further that any delay in the reduction of the emissions will be dangerous and costly (IPCC, 2011). The endeavour to control the emissions of GHGs to the atmosphere is urgent, as global mitigating efforts can enhance the prospect of sustainable development by reducing the threat of the adverse impacts of climate change. Co-benefits can also be provided through the mitigation processes such as better livelihoods and improved health standards. Thus, mainstreaming climate change mitigation is an integral part of sustainable development.

In attempting to mitigate climate change, the energy sector has a pivotal role to play. Biogas technology has a duo important climatic effect and therefore, a mitigating mechanism against global warming and climate change. In converting methane into fuel, the use of biogas reduces carbon dioxide emissions through reduced demand for fossil fuel and fuelwood. A study done in Nepal indicated that a biogas plant of 6 m^3 can potentially save about 32 litres of paraffin (kerosene/Paraffin) and more than four tons of fuelwood (Mendis and van Nes, 1999). Using manure for biogas production has triple benefits: it represent a valuable starting point in mitigating methane from the atmosphere; it is locally affordable and available raw material for bioenergy production and the slurry can be used as fertiliser compost. Renewable energy also has the potential of creating employment, enhancing energy security, mitigating climate change while also enabling developing to make substantial foreign exchange and savings (UNEP, 2012).

2.8.1 Impacts of energy extraction

2.8.1.1 Air pollution

In most rural areas, cooking is done indoors, usually outside a tent or the kitchen and majority of the houses are built without a chimney, to aid the escape of smoke. In Southern India, for example, cooking hours per household in a day range between 3.3 to 4.6 hours (Venkataraman *et al.,* 2010). Females who are mostly engaged in cooking activities are exposed to smoke from biomass combustion due to the long period of time they spent in the kitchen. When fuelwood is burnt, it emits pollutants such as organic compounds, particulate matter, nitrogen oxides, carbon monoxide, methane, and other non-methane compounds (Venkataraman *et al.,* 2010).

Fuelwood that is not entirely or properly burnt is diverted into products of incomplete combustion, which mainly produces carbon monoxide but also benzene, hydrocarbons, formaldehyde, butadiene and other compounds which poses health hazard threats. Single indicator of health hazard from smoke is thought to be small particles which contains lot of chemicals (Smith *et al.,* 2004).

Risk assessment by the World Health Organisation, which combined results of many published studies (Ezzati *et al.,* 2002), compared illness burden and premature death arising from fuelwood combustion and other major risk factors, which includes tobacco smoking, hypertension and outdoor air pollution. The results revealed that the use of solid fuels may be accountable for about 800 000 to 2.4 million premature death yearly (Smith *et al.,* 2004). The burning of biomass as fuel has been associated with diseases such as low birth weight in babies exposed to smoke from expectant mothers, cataracts, tuberculosis and other health conditions revealed in a number of other studies (Smith *et al.,* 2004).

The burning rate (kilogram of fuel burnt per hour) of biomass also affects the emissions of smoke and pollutants, as well as the thermal efficiency. In areas of high population density, the heavy use of fuelwood releases large amount of fly ash into the atmosphere. A study in Missoula, USA indicated that in summer, 55% of the particles in the air were a direct results of burnt fuelwood. However, in winter, it was responsible for 75% of the particles found in the air. In Asia, households rely mainly on fuelwood using traditional stoves. These stoves burn the wood incompletely, due to their low efficacy thus leading to emissions of pollutants (Enger and Smith, 1995).

2.8.1.2 Deforestation

On the African continent, 21% of the land area, representing 635 million hectares, is occupied by forest and equals 16% of the global forested land. Furthermore, approximately, 23 million hectares of the total forested land disappear in the 80s while another 20 million hectares of land was used in the 90s (FAO. 2006). Recently, the estimation shows that about 4 million hectares of forest land were lost between 2000 and 2010 which equal one-third of the total deforested land. The rate of reforestation is estimated currently at 0.4 to 0.8% yearly and it is expected to continue at this level. Regarding these estimations, several uncertainties are attributed to the figures and it could only be understated (FAO, 2009). Generally, in Africa, in the last fifteen years, progress towards forest sustainable management appears to be limited. However, there are few indicators that show that the forested net loss has slowed down and forest areas designated for biological conservation has slightly increases. The fact remains that in Africa, particularly during the 1980s, 1990s and early 2000s, the permanent and rapid loss of forested areas represent the highest percentage compared to any regions of the world (FAO, 2016).

Fuelwood extraction across Africa plays a significant role in deforestation (Geist and Lambin, 2002). In Africa, wood extraction for domestic fuel and charcoal production remains a major concern because most households in the rural areas still rely on wood and charcoal for cooking due to unavailability of other sources of energy or due to expensively cost associated with the alternatives. In recent years, the steady removal of wood in Africa is reported to have risen from 52 000 to 69 000 hectares. Collection of fuelwood as an energy source is increasing due to decline in productivity and thus there is a subsequent decline in income. This means there is much dependency on off-farm employment such as increment in charcoal production and fuelwood collection (FAO, 2009). Estimation is that most of the harvest wood in the rural areas is used as fuelwood. As most of fuelwood gathering activities are not recorded, the actual quantity of woods removed may be understated (FAO, 2017).

Asia represents the region with greatest use of wood as fuel. However, unlike in Africa, where most of the wood production are at a small scale, much of the wood production comes from large plantation in Asia. Roughly, there are about 8 million hectares of wood production in the world, with 6.7 million hectares an area bigger than West Virginia in the United States is located in Asia (FAO, 2010). Most of the wood planation are located in India and China and have depleted most of their forest resources. Some empirical evidence exists that the plantation helps in alleviating the strains on natural forested land (Kohlins and Parks, 2001). In regions where fuelwood is harvested from plantations, it is used mainly in crop preparation (for example, tea, coffee and tobacco) and for bricks burning and ceramic industries. In India however, nearly two-third of the plantation are for non-industrial purposes and the wood ae used by families and communities members (Brown *et al.,* 1999). As in Africa and Asia, most of the rural populace rely on fuelwood as their fuel source, although this is declining in most regions (Arnold *et al.,* 2006).

2.8.1.3 Hydrological impacts

Deforestation disrupts the water cycle because when part of the forest is removed, the affected area cannot hold much water as before. In so doing, a drier climate is created. Water resources affected due to deforestation include aquatic habitats and fisheries, drinking water, drought/flood controls, dams and waterways. The water siltation becomes less appealing to water-related recreations. These practices damage crop production and irrigation systems from turbidity and erosion (Bruijnzeel, 2004).

The relationship regarding forest and rainfall, the main considerations is the sudden movement of air upwards over the forest area which can trigger and initiates rain fall due the building of cumulus clouds. More so, a forest is more effective than other types of vegetation in trapping precipitation especially cloud, moisture and cloud. In the late 1980s. There has been a severe decline in rainfall in the Sahel parts of Africa, which includes Mozambique, Zambia, Mauritania, Niger, Chad, Zimbabwe, Eritrea, Wallo and Tigray Provinces of Northern Ethiopia were all associated with deforestation (Boahene, 2008).

Moisture balance is associated with forest that has a high soil permeability in its catchment areas and thus reduces catastrophic risk of low flows and floods. Rivers in high forest areas and high rainfall have a higher discharge, in relation to their drainage areas as compared to in deforested or semi-arid areas. About 90% of the total river length in Africa are in small streams and these streams are severely affected by changes that occur in vegetation cover. The Tana (Kenya), Rufji (Tanzania) and the River Niger which are large rivers have been affected by weather conditions of wet/dry areas through which they flow (Maingi and Marsh, 2002).

2.8.1.4 Biodiversity loss

A forest in the tropics serves as storehouse for biodiversity thus the consequent deforestation leads to degradation and fragmentation of the forest, which destroys biodiversity, leading to migration of species, including those that are endemic and endangered. About two-thirds of all known species are supported in the tropical forest and contains about 65% of the world's total 10 000 endangered species (Myers and Mittermeier, 2000).

According to the World Health Organisation (WHO), about 80% of the world population relies on forests for their primary health care, through traditional medicine. Thus, biodiversity loss and related large changes in the forest cover could trigger unexpected, harmful and irreversible changes, such as regional climate change, which include feedback effects that can theoretically shift rainforest to savannah (Myers and Mittermeier, 2000).

2.8.1.5 Soil erosion

Deforestation can also lead into watersheds, triggering the cessation to regulate and sustain the flow of water from rivers and streams. Once a forested area is deforested, too much water can result in flooding the downstream, which can steer disaster in many parts of the region. The downstream flow can also cause soil erosion, silting of water course, dams and lakes. Flooding as a result of deforestation can increase due to one or two reasons. Firstly, with smaller fountain of trees, water is likely to saturate the soil. In wet season, the sponges are filled up quickly leading to additional precipitation run off hence increasing the flood risk. The second effect is that, often deforestation result in soil compaction, whereby the soil is unable to absorb rain. Ordinarily, this can cause stream flows in faster response to rain and hence push flash flooding potential (Chomitz *et al.,* 2007).

In the river basin of Yangtze in China, due to deforestation in the river basin, the percentage of other land use changes has increased tremendously and subjected to soil erosion. In the long run, thus contributes to siltation. The heavy siltation has resulted in increased risks of flooding due to the raised river bed. Another major river basin in the humid tropics has been affected by deforestation in the Amazonian basin and the East Asia (Yin and Li, 2001).

2.8.1.6 Burden of fuelwood collection

In developing countries, dependence on biomass is an exhausting, time consuming task and burden to females and children whom engaged in the collection of fuelwood. On record, the average fuelwood headload in Sub-Sharan Africa is around 20 kg but headloads of 38 kg have also been documented (Rwelamira, 1999).

In Orissa in India, during the late 1980s tribal females were involved in the collection of fuelwood. In collecting fuelwood, the distances walked by these females became difficult as they went further away from the villages to reach the receding tree line. Over a twenty year period from the mid-1980s, the average distance walked increased to 7.0 from 1.7 kilometres. The obvious result of this was that the females had less time to care for themselves, even when ill, as large part of collecting fuelwood rested on them (Parikh, 2007).

The women suffer physical damages from strenuous work without sufficient recovery, due to the long walks. This risk of assault or falling, increases further as they have to walk long distances (Parikh, 2007). For instance, due to agricultural lands being converted to other purposes in the central region of Singida in Tanzania, the rural women walk an average distance of over ten kilometres daily, in search of fuelwood, followed by the western region close to Lake Tanganyika, where the women walk for over five kilometres daily (FAO, 2006).

The time for fuelwood collection has a significant opportunity cost on women and children. In addition, their opportunity to engage in other income-generating activities and education is limited. Many children, girls especially, are withdrawn from school, in order for them to attend to house domestic chores, which are fuelwood related, thereby limiting, reducing their literacy and also restricting their economic opportunities. However, the use of modern energy carriers can promote economic development by improving their capital and labour productivity. Using more efficient technologies can provide energy services at a lower cost, free-up household time for women and children to be more productive and ensure higher energy quality (Victor, 2005).

Significantly, there are more developmental strides to gain from expanding access to the use of modern energy services such as biogas technology. The United Nations Millennium project emphasized that direct links exist between energy and Sustainable Development Goals (SDGs). Using modern energy services can help reduce poverty and play a critical role in improvement of education opportunities in children, female empowerment and promoting gender equality. Adequate and available clean energy is important in child mortality reduction. A reduction of the carrying of heavy headloads of fuelwood improves mental health. Inefficient and incomplete combustion of fuelwood exacerbates respiratory diseases and other illnesses. Improved cooking stoves efficacy and a substitution of fuel would help in alleviating environmental damage resulting from fuelwood use. Finally, a rally point for global partnership can be achieved in the widespread substitution of traditional biomass to modern energy systems.

2.8.1.7 Health and nutrition cost

Due to the fuelwood collection burden, it can be easily visualised that there is a direct and indirect cost to factors such as cooking less food. Thus, there is a shift from meals that requires more cooking time due to increases in the workload and the burden suffered by the women who are responsible for the collecting fuelwood. There many references in the literature that families eat once instead of two cooked meals due to lack of fuel (FAO, 2004).

Due to the fuelwood collection burden, there is a selection of food that requires less cooking time, instead of those with longer cooking times. It is believed that fuelwood collection burden leads to substituting customary food with prolonged cooking time. Besides the burden of fuelwood collection from long distances, which aggravate fatigue and backaches, using fuelwood for cooking also impacts health negatively. Smoke from combustion causes chronic bronchitis, eye irritation, emphysema, skin infection, respiratory disease and headaches with children and women suffering the most (Smith *et al.,* 2004).

2.9 Knowledge Gap

The literature around the globe has shown that biogas technology is not at the expected level, despite its potential with few studies exploring the factors for the low adoption of biogas technology. In addition, there are policies in support of rural energy investments and institutional mechanisms, which have been built by the government and private sector in South Africa. However, the energy crisis provides a conducive entry point for an integrated program in the country. There are also favourable conditions for the production of biogas energy in the country, which includes availability of abundant biodegradable animals and crops waste materials.

Notwithstanding the demonstrated advantages and experience of biogas production and utilisation as a renewable source of energy and as a good waste management strategy, the energy potential of the technology has not been fully tapped in South Africa, and in Limpopo Province, in particular. This is because development and utilisation of this desirable, modern, ecology-oriented and friendly form of appropriate technology remains low and its adoption remains dismal. Biogas energy production and utilisation still do not have a footing in South Africa, mostly in the rural areas. Furthermore, the socio-economic and environmental potential of the technology has largely remained elusive.

The reasons for this trend remain by and large obscure. This research, therefore, attempts to address the gap by evaluating the socio-economic factors mitigating against the adoption and utilisation of this technology in Limpopo province. It also seeks to find out which model may be developed to promote the adoption and utilisation of the technology. It seeks to establish why has the technology failed in the country, despite the prevailing conditions that are favourable to its development as well as how viable is biogas technology as an alternative source of energy. It also seeks to establish the perceptions of households about the technology in Limpopo Province. Finally, it seeks to estimate the greenhouses gases emitted from the study because of fuelwood consumption for domestic purposes.

Furthermore, there is no available substantive data in the province regarding greenhouse gases emissions resulting from substituting fuelwood for biogas technology. Therefore, quantifying the amount of fuelwood saved in households is vital, in order to understand/establish the level of greenhouse gases emission reduction due to the adoption and utilisation of biogas technology. Therefore, there is a need for significant advancement in understanding the innovation and transaction of biogas technology. Implementing the technology will inform the policy and practice that drive government and non-governmental organisations in approaching and adopting alternative energy technologies, particularly renewables.

2.10 Conceptual Framework

The theoretical lens from this study perspective emanated from the adoption of innovation model as propounded by Rogers, (2003) also referred to as the Innovation-Decision Process and the Theory of Economic Constraints as propounded by Goldratt, 1984. The economic constraint theory contends that the distribution of resource endowments among the potential users determines the pattern of adoption of a technological innovation.Adoption of innovation entails the whole sequence of events occurring to an individual, from the time one becomes aware of an innovation, until the adoption stage. The whole process is referred to as the innovation-decision process, which may involve knowledge, persuasion, decision, implementation and confirmation stages (Rogers, 2003). In this process, an adopter goes through different stages, whereby awareness is the first stage and adoption in the last stage.

At the awareness stage, people get general information about a new idea, product or practice for the first time, but not its details. As people are not satisfied merely with knowledge or general information, they need and actively seek additional and detailed information about the innovation (interest stage). With the detailed information, people decide whether the idea is good or not (evaluation stage) after which the potential adopter would try the new idea or practice a little later (trial stage). After successful trials, usually on observing and or consulting with others, people may take up the innovation for full use (adoption stage). Depending on the nature of innovation, some stages may be skipped and the most frequently skipped one is the trial stage, due to difficulties in trying a little first and more, later on (Rogers, 2003).

Technological adoption frameworks are systems information that provides theoretical bases in examining certain factors that influence the adoption of technology. Several popular models and theories have been used in investigating adoption behaviour of individuals or organisations. Technology adoption by a perceived user depends on many factors that lead to its adoption or rejection. Such factors include but are not limited to technical difficulties, user involvement, lack of understanding and lack of training, lack of support and complexity of the technology, which can lead to the success or failure of the intended technology. Technology adoption incorporates incidence, intensity and adoption rate. In relation to incidence, it is the percentage of people using a specific technology at a specific point in time. Intensity relates to the adoption level of a particular technology while the adoption rate refers to the proportion of people whom have adopted the new technology over time.

Different statistical models, such as log-linear regression, discriminant analysis, probit regression or logistic regression, can be utilised in the analysis of binary discrete responses. In log-linear regression, all variables are required to be categorical, while discriminant analysis demands firmly that all independent variables be continuous. Nevertheless, in cases where both probit and logistic regression is applied, the independent variables can be continuous and or categorical (Singh, 2007). In attempting to model dichotomous variables that are dependent, two models are commonly used and appropriate. These are the logit and probit models (Spuchľaková & Cúg, 2014). The choice between using the logit or probit models depends largely on convention and convenience.

The logistic model is applied practically in cases that required explaining the dependent variable is not continuous but rather binary. Maximum likelihood estimation is applied after the dependent variable is transformed to a logit variable (Garson, 2008). Characterized by logit model is the prediction probability that an event could either occur or not. Thus, the calculated probability is equal to 1 or 0. The transformation of the logit is based on the ration of hopes and chances which in transformation, allow an ideal relationship between the dependent variable “y” and the vector of the independent variable “x”. When the values of the independent variable are low, the probability is variable “y” is close to 0 and if the value of the dependent variable are high, then the probability is that “y” is close to 1. Categorically explained variables are used in the logit model (Kollár, 2014). The alternative to logit model is the probit model. The core variance is that normal distributions of random variable are assumed in the probit model and logit model function has harder “fat tails” while the probit has a steeper slope in it distribution function”. In practice, there is no significant difference between both model, except in cases where the sample contains extreme value in the numerous observations. Estimated parameters obtained by both models cannot be directly compared because the logarithmic distribution are of variance; thus the obtained estimates by the logit model have to be multiplied in order for them to be comparable with the obtained estimates from the probit model (Lehútová, 2011). Despite the mutual similarity between both models, practically, the logit model has two advantages over the probit model, which are simplicity and interpretability. The simplicity of the logit equation distribution function is simple, while the cumulative normal distribution contains unquantified integral. In interpreting the logit model, the linear inverse transformation can be directly interpreted as logarithm of chances, while the probit model inverse transformation does not have direct interpretation.

Both models have been used in the study of adoption of technology. However, the basic underlying assumption in the discrete choice theory is that rationally, consumers select from a list of alternatives and choose the one, which has a higher utility level. It is assumed that the collection of a technology by household is ranked indirectly through the characteristics they poses, which influence the adoption decision based on the number of characteristics the technology represents (Garson, 2008). The often-considered variables in the decision to adopt a biogas technology include educational level, age, household size, level of income, gender of household head, among others (Somda *et al.,* 2002). Explanatory variables are also used in the adoption process. This, however lacks a strong theoretical basis perhaps because households deliberate on varieties of issues that are beyond socioeconomic motivations, which include non-economic factors. The management and development of biogas technology are mainly from a technical point of view and always involve the social and economic problems as well as human behaviour characteristics (Mendola, 2007).

In literature, considerable amount of adoption behaviour postulates that personal, economic, social, technical and institutional factors are key elements in the adoption process (Bekele and Drake, 20030). In India, different comparative studies on biogas plant models by Singh and Sooch, (2004), emphasised the significance of determining the economic viability of a biogas plant as an important factor in the development of the technology. In addition, Srinivasan (2008), observed that domestic biogas is justified, due to benefits accrued to the households. Hall *et al.,* (1992) asserted that many developing countries lack adaptation and improvement of the technology for modern biofuel, due to contentious issues associated with adoption. A technical assessment and analysis of the Saveh biogas plant in Iran revealed several benefits of using a biogas plant. These include improved soil moisture from the slurry, solid waste treatment, income generation, agricultural productivity, as well as environmental benefits. Furthermore, case scenario analyses conducted by Akinbami *et al.,* (2001), who examined the prospects and future of biogas technology in Nigeria. The results indicated and recognised that the utilisation and development of the technology remained untapped due to lack of information, high investment capital costs, design types and building materials as well as socio-cultural factors, were the potential factors that have hindered the low adoption and dissemination of the technology in that country.

Three important factors were identified for the successful uptake of biogas plants in Denmark. The Danish government applied the bottom-up strategy that motivated interactions and learning of the technology among various social groups. Secondly, a committed social network that ensured a continuous growth of the technology without disruption. Thirdly, specific local conditions were considered (Raven and Gregaseen, 2007). Recommendation measures to promote renewable energy sources and biogas in Thailand include creating incentives platform that will encourage the purchase of power generated by renewable energy. These include credit tax and privileges, encouraging the partnerships and participation of local communities in renewable fuelled power plants and grants and subsidies from the energy as well as Conservation Promotion Fund (CPF), to support research and development in the areas of renewable energy such as biomass, agricultural and municipal wastes (Prasertsan and Sajjakulnukit, 2005).

In the study on the individual effects on the economic status of the adoption of biogas technology, Ni and Nyns (1996), asserted that acceptance of biogas technology was mostly in the middle-income class. A survey in Asian and African countries conducted by GTZ indicated that from the 610 adopters of the technology, only 5% were low-income earners. From the survey, it was difficult to achieve a regular operation after initial installation. This points to the importance of appropriate management of the plant, in order to succeed in the plant production and utilisation. Studies have also indicated that in some cases, non-technical issues, that include loss of interest by owners of the digesters, are other factors that lead to the failure of continuous operation of the digesters. At community level, the availability, sources and prices of conventional and traditional energy are pivotal in the adoption and utilisation of the biogas technology. These parameters vary in from community to community, such as fuelwood price, cooking stove efficiency and others. (Ni and Nyns, 1996).

The conceptual framework that guided this study is illustrated in Figure 2.10. The framework focuses on the institutional roles in terms of policies and regulations, effectiveness of the major players in motivating, organizing training workshops, advertisement and the role of the media in the adoption and utilisation of biogas technology. In addition, the promotional factors in the adoption or non-adoption of the technology are influenced by socio-economic, technical and environmental factors, which are paramount in technology awareness, knowledge and benefits and attitude towards the technology. The adoption of a technology such as biogas can greatly increase the agricultural productivity of the adopting communities through the production of slurry that can be used as fertilizers. Thereby, reducing air pollution, by averting the use of traditional fuels, such as fuelwood, which are associated with emissions, and other related health hazards, such as eye irritation, asthma, coughs and underweight in new-born babies. The adoption will reduce poverty and improve the health of the adopters, as the time spent in the collection of fuelwood can be channelled into other productive economic activities. This will lead to sustainable development.

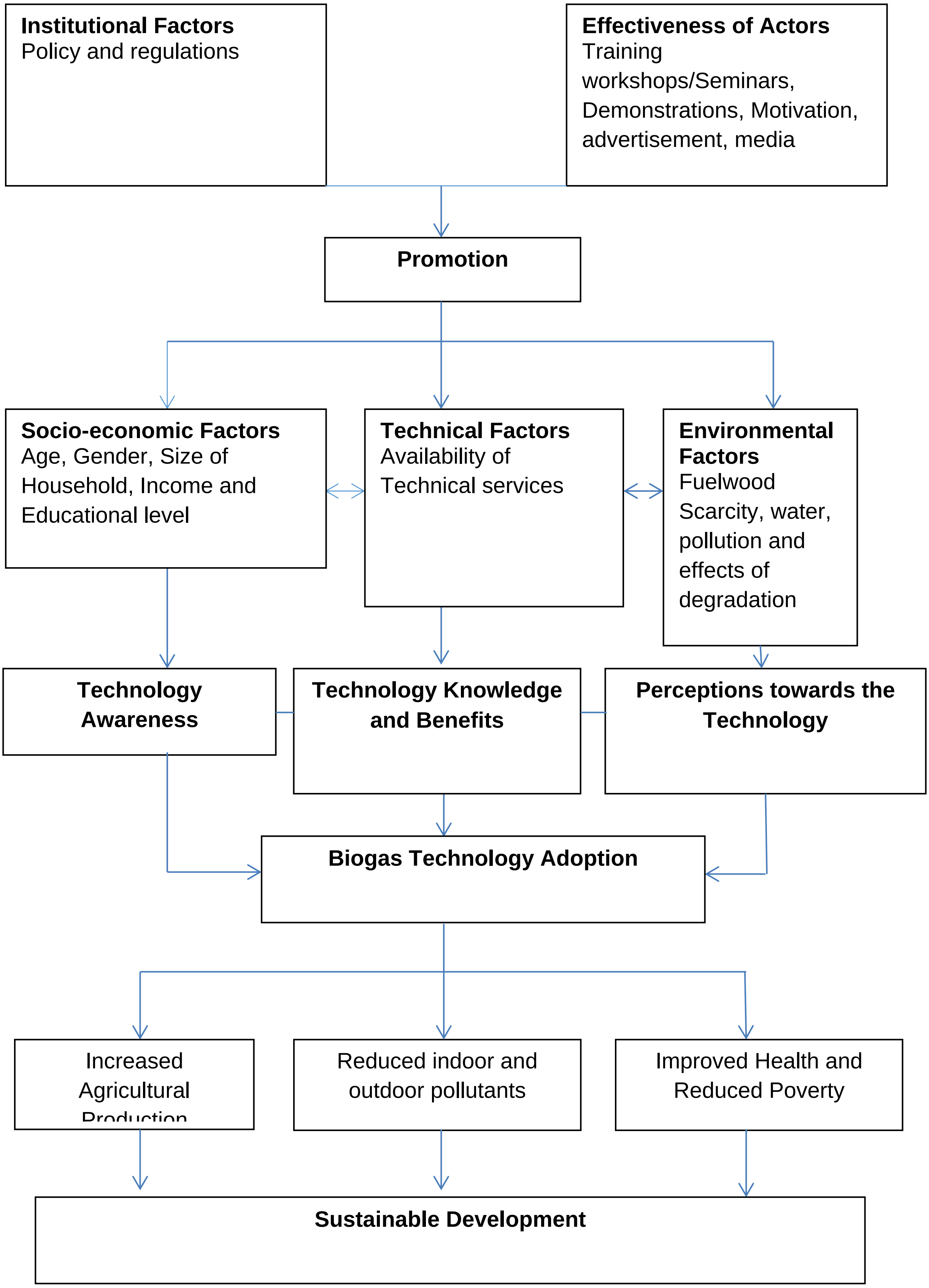


Figure 2.10: Conceptual framework of biogas technology adoption.

2.11 Summary

This literature review chapter focuses on the conception of biogas technology in the world and South Africa, the various types, designs and the mechanism of the technology through the production of anaerobic digestion. Further assessed in the chapter is the literature is the decision analysis of technology adoption with the review of the theory of reasoned action, diffusion of innovation, technology adoption model and the unified theory of acceptance and use of technology. Furthermore, this chapter also brought to light the factors influencing the adoption and utilisation of technology from the perceptions of socioeconomic characteristics, institutional characteristics, technology characteristics, geographical and environmental characteristic, as well as the role of government institution in the dissemination of technology. The review also critically examines the impacts of energy extraction in air pollution, deforestation, hydrology, biodiversity loss, soil erosion burden of fuelwood collection and health and nutritional cost. The theoretical framework that guided this study was likewise evaluated in the literature review section. The theoretical lens from the study perspective emanated from the adoption of innovation model as propounded by Rogers, (2003) that is sometimes referred to as the Innovation-Decision Process and the Theory of Economic Constraints as propounded by Goldratt, (1984). The economic constraint theory contends that the distribution of resource endowments among the potential users determines the pattern of adoption of a technological innovation. This literature chapter lead to the next chapter that draws detailed philosophy of the study design and research methodology employed in the thesis.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter provides an explanation of how the study was conducted. It includes the sampling procedures, types and sources of data, techniques of data collection and the methods used in processing and analysing the data.

3.2 Research Design and Approach

The research employed a descriptive design, utilising a case study approach, in which allows an in-depth exploration of the activity of one or more individuals. The case study design is bounded by time and activity, as it allows the researcher to collect detailed information using varieties of data collection methods and procedures over a sustained period of time (Stake, 1995).

The research approach is a triangulation of both qualitative and quantitative methods, as it offers a logical informative statement that helps the researcher centres the inquiry on the notion that diverse collection of data will provide a better understating of the research problem. The use of the mixed method is due to the diversity of information required to answer the objectives of the study.

A blueprint or a framework for mapping how a study is going to be conducted is referred to as research design. Creswell (2013), defined research design as plans and procedures that expands decision from wide assumptions to exhaustive methods in collecting data and analysis. A research design is the logical or master plan of the research, specifying the connectivity of the research and it works together in attempting to address the objectives of the research. Triangulation of quantitative and qualitative techniques, concepts approaches and methods in a single study was utilised, as neither methods can achieve the objectives of the study completely. Triangulation offers a researcher the chance to integrate a research problem, as in cases such as adoption and utilisation of biogas technology due to its intricacy. Nonetheless, when applying both methods, each are complemented and therefore gives room for a more complete analysis.

Yin (2011), regards qualitative research as a system that attempts to attain and understand the fundamental motivations and reasons for action and thus, establishes how people's experiences are interpreted in the world around them. The qualitative aspect of this research was instrumental in attaining a clear understanding of the respondent's views, attitudes, perceptions and interpretation of biogas technology introduction in Limpopo Province.

Through the qualitative approach, the researcher undertook an in-depth synthesis of related variables to biogas technology adoption and non-adoption. Consequently, a combination of observations, document reviews, questionnaire and interview survey was employed. The interviews were directed to stakeholders who were purposively selected as relevant key informants because of their perceived knowledge in biogas technology. More so, the open-ended questions were used to elicit information from non-adopters and adopters of the technology, using a household structured questionnaire. These research instruments were contributory in the collection of date on correlating factors influencing the uptake of biogas technology, resource availability, awareness and perceptions, biogas technology experience as well as the promotion of biogas technology among the households.

In addition, the quantitative method played a vital role was played in collecting data for the study. In quantitative research method, the premise is on the numeric expression of data, therefore making it predisposed to statistical analysis. The quantitative data were collected using closed-ended questions on the questionnaire. The elicited information included socio and demographic questions of the surveyed households, the estimation measurement of fuelwood used before and installation of a biogas plant. Also solicited were cross cutting information related to factors influencing the adoption of the technology, as well as awareness and perceptions, which were separate variables and casually related in determining the frequency and magnitude of statistical relationships.

The triangulation research method was best suited for this study, as it ensured that the qualitative and quantitative data were obtained from open and closed-ended questions respectively. It allows the researcher to define which variable to examine and choose the appropriate instruments which will give effective tallies and trustworthiness and provides the much needed explanations and descriptions of the problem under study. The approach also allows the use of words and numbers in solving complex research problems and further combines deductive and inductive thinking (Creswell, 2013).

3.2.1 Sampling Procedure and Size

According to Prabhat and Pandey (2015), a research population refers to the entire cluster of people or subject totality or objects under investigation that conforms to set of specifications that are of importance to the researcher. Therefore, the sampling population is defined as the unit of the entire population to which inferences are drawn by the researcher (Yin, 2011). Thus, the target population for this study were primarily households in villages in Limpopo Province that have adopted biogas technology and households in villages to which the technology has been promoted. The choice of households was justified on the assumption that they have first-hand information, which is critical in making decisions related to biogas technology adoption and utilisation.

The study sample population was drawn from households in the Limpopo Province comprising Vhembe, Waterberg, Capricorn, Mopani and Shekhukune districts. Eleven villages in the province were identified for this study specifically because they had been targeted specifically for the promotion and development of biogas technology through the introduction of demonstration digesters. The villages were Gogogo, Maila, Shewela, Muyexe, Xhivulani, Thomo, Gaula, Mphambo, Mhinga, Dzwerani and Chavani. From the aforementioned villages, only Chavani had not been reached with a biogas demonstration plants. However, awareness seminars and workshops had been held in the village. The village was included in the sample in order to ascertain their perceptions towards the technology. The biogas project was promoted by National Research Foundation (NRF), Water Research Council (WRC), Limpopo Department of Economic Development, Environment and Tourism (LEDET), University of Venda, Mpfuneko Biogas project (NGO) and the Agricultural Research Council (ARC).

The selection of study units from a defined population is called sampling. A research sample is the entire population subgroup from which data are collected and generalisation is made. If the study population is small in number, it is preferable to sample the entire population, rather than sampling a unit as it gives a high accuracy level and provides complete statistical coverage (Creswell, 2013). As a result, 72 households with biogas digesters and 128 households without digesters were drawn as the sampling units. Purposive sampling technique was employed for households with biogas digesters.

The stratified sampling technique usually requires a smaller sample, to ensure that the various subpopulations are included in the sample, and it is more representative of the population than a sample chosen using simple random sampling if the information in the stratum is accurate (Neuman, 2011). The sample was chosen because of the simplicity of the technique and its ability to provide equal opportunity for the non-adopter households to be included in the sample, while having a low sampling error (Suri, 2007). Systematic and cluster sampling can be used together with simple or stratified sampling, or even in combination with each other. Although simple radom sampling takes up less time and money, it still yields accurate results (Huysamen, 2004). This sampling technique was employed for households without biogas digesters.

The method of sampling could not be entirely based one sampling technique because the number of households with biogas units in relation to those without biogas units in the province were too few and thus a stratified sample could not be drawn from the population. The basis of this analysis is based on a final sample of 200 households from the province, comprising of 72 households with biogas digesters and 128 households without biogas units. From the households with biogas digesters, at least one household without a digester was randomly chosen, in order to elicit their view of whether a household with a digester influences their perceptions about the technology. These instruments were developed on the basis of the research objective and reviews of the literature related to the adoption of technology, which were pretested before the actual field survey.

Table 3.1: Total sampled households in the study.

Village	**Sampled households with digester**	**Sampled households without digester**	**Total**
Gaula	31	12	43
Maila	1	04	05
Gogogo	1	05	06
Xhivulani	9	12	21
Mhinga	1	07	08
Dzwerani	1	04	05
Mphambo	4	12	16
Thomo	1	18	19
Shawela	19	09	28
Chavani	0	33	33
Muyexe	4	12	16
Total	72	128	200

3.2.2 Ethical Considerations

Ethical considerations were followed, and permission was obtained before field visitation. Ethics in research refers to set of principles and moral that are acceptable, which govern the conduct of a research, with particular reference to the stakeholders and the sample population. According to Yin (2011), a study should be designed, reviewed and undertaken to ensure quality and integrity. Lupele (2002) emphasised the need to seek permission from tribal authorities or leaderships in their rural set up before conducting research. The purpose of the research was explained to the authorities and leadership who then publicised the aim of the study among their residents and encouraged them to give their full cooperation. The research consent form was fully explained to the respondents and they were informed that they were free to withdraw from participating if and when they saw the need to do so.

Confidentiality of the participants remained paramount in the research and rights to anonymity, self-determination and informed consent were strongly observed throughout data collection. Furthermore, the study was non-invasive and no risk was involved for the participants. The participants consented willingly to partake in the data collection processes. Prior to engaging the participants, the researcher obtained a consent letter from the directorate of research and innovation, which was issued by the University Research Ethics Committee.

3.2.3 Research assistants

A total of three research assistants conducted the data collection. It was the researcher and two assistants. The research assistants were engaged to help in the facilitation of the research instruments due to their proficiency in English and the local languages, their familiarity with the study area in socio-cultural and geographical settings. The research assistants had past experiences because they have been engaged in previous field work and thus exhibited professional and intellectual conduct that is expected to cope with tasks associated with household surveys. In order to maintain a high standard and credibility in the data collection, the need to eliminate bias was highly emphasized.

3.3 Data Collection Methods

The household surveys were conducted from the year 2017 to 2018. The data were elicited using primary and secondary methods. The purpose of the study was to conceptualize the adoption and utilisation of biogas as clean, cheap and sustainable alternative energy source for emissions reduction in rural Limpopo villages.

3.3.1 Questionnaires

The designed questionnaires were self-administered to 200 households in the Limpopo Province. A questionnaire is a research instrument that consists of a series of outlined questions that serve the purpose of gathering relevant information from the respondents. The questionnaire was opted for because it is relatively cost effective and allows a large amount of information to be captured from a large number of respondents in a short period. The questions included age, educational level, income, household size, number of livestock owned among others. The question were designed to include open and closed ended questions that were divided into four parts (A); demographic and socio-characteristic information (B);

resource availability (C); awareness and perceptions of biogas technology (D); biogas technology experience (E); promotion of biogas technology.

Crucial to the survey were the open-ended questions, which gave the respondents the freedom to express themselves freely. This is because respondents can provide answers in their own words and be able to clarify issues relating to the question asked. The questionnaires were administered to the households to give clarification where needed, with the aid of research assistants where in instances the respondents did not understand the English language in such cases. The research assistants had to translate to Tshivenda or Xitsonga which were the local languages in the study area.

3.3.2 Interviews

Semi-structured interviews were employed in the study as another instrument for data collection. According to Yin (2011), the interview method allows the research to have engagement with key informant with profound experience and knowledge about a particular phenomenon. The interview is thus an in-depth qualitative discussion with a person with practical knowledge of the concerned issue. The interview method was opted by the researcher to supplement obtained data from the questionnaires and relatively to its strength and cost-effectiveness in capturing empirical data in formal and informal settings (Prabhat and Pandey 2015). The interview was structured with a guide that consists mostly of open-ended questions (Appendix 2). The idea of open-ended question was ideal for collecting detailed explanatory data on the respondents' preference and opinion on energy. The adopted interview method proved to be useful, as it allowed the researcher to have one-on-one interaction with the respondent. It also showed flexibility, as it gives room for questions to be adjusted and provides clarity where needed.

3.3.3 Field Observation

The field observation was used in identifying some of the existing impacts, such as the extent of degradation of the forest due to fuelwood harvesting. Field observation helps in gleaning information that could not be gathered through the administered questionnaire or from reviewed literature. Field observation was used to evaluate the existence of biogas digesters, designs and inputs used in generating gas. Field observation enabled the researcher in establishing first-hand information regarding functioning and non-functioning biogas digesters in the sampled households. Field observation helped the researcher to observe events as they happened (Yin, 2011). From the observation, the amount of fuelwood consumed by households was measured using a spring balance, storage, vegetation cover in the area feeding and the general handling of slurry from the digester. Field observation provided room for the researcher to bridge the gap between interviews and the administered questionnaires. During the field observation, a digital camera was used to capture moments of interest to support the findings of this study. Such captured moments include pictures showing piles of fuelwood, where fuelwood is used for cooking, biogas digesters, stoves and farming areas among others.

3.3.4 GHG Emissions Estimation Measurement

Reduction of emissions is assumed to be a result of transformation of greenhouse gases from decomposition of dung into fuel by the elimination or minimization of carbon dioxide from fossil fuel and wood combustion. Fuelwood contributes to greenhouse gas emissions through the combustion of biomass and unsustainable harvesting of wood. Greenhouse gases can be measured either by recording the emissions at sources, by continuing monitoring or through the estimation of the amount emitted by multiplying the activity data (that is amount of fuel used) by the emissions factor. These emission factors allow data activity (that is liters of fuel used) to be converted to kilograms of carbon dioxide (CO_2eq), using a universal measurement unit.

To calculate the amount of greenhouse gases emitted, the amount of fuelwood used was by households was obtained using a spring balance, to measure the amount of fuelwood likely to be consumed by a household daily and the mass recorded in the questionnaire. The accuracy of this method was evaluated in Rwanda and Botswana by the African Energy Policy Network (AFREPREN) (Kgathi and Mlotshwa, 1994). Furthermore, the household rate of fuelwood consumption can be determined using the normal per capital consumption, using a simple household count. Therefore, a household’s daily per capital consumption of fuelwood can be measured.

3.4 Methods of Data Processing and Analysis

3.4.1 Data Processing

The generated data gathered from the administered questionnaires was used to establish the trends of this research. The generated data was analysed and simplified using Microsoft Excel spreadsheet and statistical procedures of the Statistical Package for the Social Sciences (SPSS 22.0). The data were coded, defined and labelled and fed in Microsoft Excel then, exported to the SPSS program, to generate descriptive statistics principally to identify patterns and trends. The results of the data were clearly displayed in cluster columns of graphs, bar and pie charts as well as simple and contingency tables. Descriptive statistical procedures and techniques such as frequencies, mean, standard deviation, and cross tabulation were also used. A Logistic Regression Model, Pearson Chi Square, Spearman Rank Correlation Coefficient and Content Analysis were also used to present a detailed analysis of both quantitative and qualitative data.

3.4.2 Data Analysis

Objective 1: To evaluate household levels of biogas awareness and their perceptions towards the adoption of the technology. A Spearman Rank Correlation was used in the analysis of the respondent's perception towards the technology. The formula for the perception Index is stated as: $PI = \sum(s_1+s_2+s_3+\ldots\ldots\ldots.s_n)$ where S = score weight for each statement. The score weight from the respondents will be summed up according to their perceptions of the technology.

The Spearman Rank correlation is given as:

$$RS = 1 - \frac{6 \sum d^2}{n^3 - n} \qquad (3.1)$$

Where d = difference in the rank of the paired values; n = is the number of pairs. The 't' test for the correlation co-efficient is given as:

$$t = rs\sqrt{\frac{n-2}{1 - rs^2}} \qquad (3.2)$$

Also, the chi square test is expressed as:

$$x^2 = \sum_{k=0}^{n} \frac{(O-E)^2}{E} \qquad (3.3)$$

Where x^2 = Chi square obtained; Σ= the sum of; O = observed and E =expected score.

Objective 2: To determine the correlating factors influencing the adoption and utilisation of biogas technology in the rural areas of the Limpopo Province.

Included in the data analysis to test the goodness of fit are the determination of percentages, means, Pearson's product moment correlation coefficient, the variables standard errors values and t-test. To compare the continuous explanatory variables between biogas users and non-users, the independent sample t-test mean values was employed to statistical test the significance of the individual parameters. Furthermore, based on these criteria, and because mixtures of continuous and categorical data are involved in the study to determine the correlating factors influencing adoption decision of biogas technology by households, the logistic regression was used because of its ease in interpretation because it has an odd ratio, which the probit regression lacks. The descriptive and explanatory variables used in the study are indicated in table 3.2 and 3.3.

Table 3.2: Description of explanatory variables used in biogas technology adoption in the study.

Variable	Variable Description	Measurability
AGE	Age of head of household	Continuous
GENDR	Gender of household head (1= male; 2= Female)	Categorical/proxy
HHSZ	Number of people in the household	Continuous
INCOME	Monthly income of household head (ZAR)	Categorical
CATTLE	Number of cattle owned by households	Continuous
CROP	Household engagement in crop production	Continuous
TECHAVAB	Technical support availability (1= yes; 0= Otherwise	Categorical/proxy
FWSD	Fuelwood collection distance and source	Continuous
EDULA	Educational levels of household head	Continuous
WATERSA	Water availability, source and distance (1= Yes; 0= Otherwise)	Categorical/proxy
SLC	Subsidies, loans and credits to household	Categorical/proxy

Table 3.3: Explanatory variables and priori signs used in biogas adoption in the study.

Variable	Expected sign
Age of heads of household	±
Gender of household heads	±
Number of people in the household	±
Monthly income of household head	+
Number of cattle owned by households	+
Household engagement in crop production	+
Technical support availability	+
Fuelwood collection distance and source	+
Educational levels of household heads	+
Water availability, source and distance	+
Subsidies, loans and credits to households	+

Associated with the logit model using the explanatory variables, the following arguments were made. Older heads of households (AGE) were expected to have more resources such as herds of cattle (CATTLE), thus creating the potential of adopting biogas technology as compared to younger household heads without cattle. Furthermore, the availability of feedstock, particularly cow dung in rural areas, is a prerequisite that will ensure the operation of a biogas digester. Households involved in crop production (CROP) are expected to adopt biogas technology as the slur from the digester will be used as fertilisers to increase crop yield. Other considered variables that can influence the uptake of biogas technology include technical availability (TECHAVAB), source, distance and access to water (WATERSA); as well as distance and availability of fuelwood (FWSDA). These are expected to influence the adoption of the technology because as the distance increases, households may seek alternative energy source such as biogas.

The level of education attained (EDULA) by heads of households is also assumed to play a vital role in influencing biogas technology adoption. Thus, educated household heads are expected to have more awareness and more access to information, and this can play a role in technology adoption. The income earned by households (INCOME) is another paramount factor that is expected to influence the interest in biogas technology adoption and utilisation. Bio-digester construction requires money and thus households with high-income levels are more likely to adopt the technology than low household earners. Financial support (SLC) in the form of subsidies, loans or credit to low household earners is expected to motivate their interest positively in biogas technology. In addition, gender of the household head (GENDR) is expected to influence biogas adoption. Furthermore, household size (HHSZ) is expected to positively or negatively influence household decision on the adoption of biogas technology.

The logistic regression model was used to determine the factors affecting adoption and non-adoption of biogas technology. The logistic regression is applied when dependent variables are in contrast and the independent variables are of any kind. In addition, it applies the maximum probability approximation after converting the dependent into a logit variable (Garson, 2008).

It approximates the likelihood of a certain occurrence of an event. The dependent variable is a logit, which is the usual log of the likelihood; that is,

$$\left(\frac{p}{1-p}\right) = a + bX \tag{3.4}$$

Extracting p from equation 3.4, it comes out as presented in equation 3.5;

$$p = \frac{e^{a + bX}}{1 + e^{a + bX}} \tag{3.5}$$

Where P is the probability of the event occurrence, X are the independent variables, e is the base of the natural logarithm a and b are the parameters of the model. In literature, there are contrasting views on the empirical form of the model PrY and P(Y). However, P(Y) was used as the empirical form of the model in the study is as follows:

$$P(Y) = \frac{1}{1 + e^{-(a + bX)}} \tag{3.6}$$

Y is the logit for the dependent variable. The logit regression model calculation for this study is given as:

$$P\ (Y) = \beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6+\beta_7X_7+\beta_8X_8+\beta_9X_9+\beta_{10}X_{10}+\beta_{11}X_{11}+\beta_{12}X_{12} \quad (3.7)$$

$$\text{In}\{P(X)/(1 - (P(X)\ \} = \beta_0 + \beta_1X_1 + \beta_2 + X_2 + \beta_3 + X_3 + \ldots\ldots \beta_{12}X_{12} + e \quad (3.8)$$

Where

P = Probability of adopting biogas technology

P = 1 Household adopts biogas technology

P = 0 Household has not adopted biogas technology

β_0 = Constant

X_1 = Age of household head

X_2 = Educational level of household head

X_3 = Gender of household head (1= male; 2= Female)

X_4 = Household size

X_5 = Monthly income of household head

X_6 = Numbers of cattle owned by household

X_7 = Household engagement in crop production

X_8 = Biogas awareness by households (1= yes; 0= Otherwise

X_9 = Technical support availability (1= yes; 0= Otherwise

X_{10} = Fuelwood collection distance and source

X_{11} = Water availability, source and distance (1= Yes; 0= Otherwise)

X_{12} = Subsidies, loans and credits to household

β_i = Estimated vector parameter

e = Error term

Objective 3: To determine the amount of fuelwood saved and emissions equivalent arising from adoption and use of biogas technology. Emission reductions are assumed to result from transforming methane into usable fuel, and eliminating or minimizing carbon dioxide through combustion. Fuelwood contributes to the emissions of greenhouse gases (GHGs) through sustainable, unsustainable harvests and combustion of biomass.

In estimating emissions amount from fuelwood, the accuracy depend largely on the data of quantities of wood consumed and the emission ratio of the corresponding trace gases of interest are required. The emission ratio is defined as the compound mass per unit of dry fuel that is released during combustion.

In the present study, the methodological generic formula, as outlined by The Intergovernmental Panel on Climate Change, was used to estimate the Greenhouse gas emissions (IPCC, 2006). The amount of carbon released from fuelwood was calculated from the total fuelwood burnt, the fraction oxidized and the carbon content in the wood was expressed as:

$$T_{CR} = B_{CC} \times O_{xf} \tag{3.9}$$

Where;

T_{CR} is total carbon released

B_{CC} is biomass carbon content (0.5)

O_{xf} is oxidized fraction of biomass (0.9)

From the fuelwood burnt, the emission of CO_2 can be estimated by converting the total carbon content (C) to carbon dioxide content (CO_2) using the conversion ratio of 44 CO_2/12 C. The equation is explained as (IPCC, 2006):

$$T_{co_2} = T_{fb} \times B_{CC} \times O_{xf} \times \frac{44}{12} \tag{3.10}$$

Where in Equation (3.10), T_{CO2} = Total CO_2 released from the fuelwood burnt, tfb = Total fuelwood burnt, bcc = biomass carbon content (0.5), oxf = fraction of biomass oxidized (0.9).

The calculation of other trace gases of non-CO_2 emissions, which include CH_4 and N_2O owing to fuelwood combustion was estimated using the following conversion (World Bank, 1998).

The amount of Methane (CH_4) is given as;

$$A_{CH_4} = T_C \times \eta(0.012 \times \frac{16}{12}) \tag{3.11}$$

Where η is emission ratio.

The amount of nitric oxide (N_2O) is given as;

$$T_C \times \eta(0.007 \times \left(\frac{N}{C}\right) \times 0.01 \times \frac{44}{28}) \tag{3.12}$$

Where $\frac{N}{C}$ is Nitrogen-Carbon ratio.

Objective 4: Develop a comprehensive conceptual framework for the adoption and utilisation of biogas technology. Content analysis was conducted in evaluating the different technological adoption models and theories.

The data collected from the interview was organised in themes and topics. For the analysis of the opinions and perceptions from the interviews, data was grouped in categories and discussed in simple descriptive narrative while the data generated from Focused Group Discussions was analysed using a Content Analysis Method by transcribing the notes into summary and drawing out conclusions (Krippernddorf, 2004). Summarized in Table 3.4 are the methods employed in a achieving the objectives and to answering the research questions in the study.

Table 3.4: Summary of Research Questions, Methods and Procedures, Unit of Analysis and Data Analysis.

Research Questions	Methods and Procedures	Unit of Analysis	Data Analysis
What is the household's level of biogas awareness and their perceptions towards the adoption of the technology?	Questionnaires and Interviews.	Household.	Frequency distribution, chi-square and spearman rank correlation co-efficient using SPSS.
What are the determining and correlating factors influencing the sustainable adoption and utilisation of biogas technology in the rural areas of the Limpopo Province?	Questionnaires and Interviews.	Household.	Frequency distribution, logistic regression model using SPSS.
What is the amount of greenhouse gases emitted from fuelwood in the study area?	Measure and weigh the amount of fuelwood used before and after the installation of biogas plant.	Measured weight and amount of fuelwood.	Calculate the total carbon dioxide, carbon monoxide, nitrogen oxide and methane emitted from the fuelwood, using IPCC guidelines.
Which conceptual framework is suitable for the adoption and utilisation of biogas technology in the province?	Documentary review		Content Analysis.

3.5 Summary

This chapter detailed the methodology and the instruments used for data collection among the respondents from the sampled villages. The chapter focused on the methods explored to achieve the specific objectives of the study, which are inherent from the main objective, which is development of a conceptual framework for adoption and utilisation of biogas as an alternative source of energy for emission reduction in the Limpopo Province.

The research design adopted for this study is a case study and a quantitative analysis approach. The period of data collection for this study span through 2017 to 2018. Accordingly, the data collection mainly involved households with biogas digesters and households without biogas digesters. 200 households were sampled using questionnaires, interviews as well field observation in order to elicit their awareness and perceptions, correlate the factors influencing the adoption and utilisation of the technology and the role of biogas technology in emissions reduction in the province.

In this study, data were collected using both methods, hence, a combination of data analysis methods were employed. Due to the inherent nature of the objectives, the analysis of the data thus was aligned to each objective. In the first objective, a non- parametric test of spearman rank correlation co-efficient and chi-square were employed to show the association between the dependent and independent variables. Furthermore, results from the analysis were displayed in simple bar char, pie and bar graphs. The analysis of the second objective involves the use of a logistic model to correlate that factors influencing households in adoption and utilising the technology. On the third objective, the generic formula for the calculation of emissions as stipulated by the IPPC and World Bank were relied on as the emission ratio of each greenhouse gas was measured. The analytical statistical procedure was done using SPSS version 22, which was used to generate the descriptive statistics principally to identify the patterns and trends of the variables. The preceding chapter focuses on the awareness and perceptions of biogas technology towards the adoption of the technology in the province.

CHAPTER 4

EVALUATING BIOGAS TECHNOLOGY AWARENESS AND PERCEPTIONS TOWARDS ADOPTION IN LIMPOPO PROVINCE

4.1 Introduction

One critical issue confronting developing nations such as South Africa is the provision of sustainable energy, where a proportion of its population do not have access to modern and reliable energy. Access to energy is viewed as a vital condition that enhances the development of a country's economic activities, in order for the people to have an improved quality of life (Scarlet *et al.,* 2015). This explains the notion why providing adequate, affordable, sustainable, clean and efficient energy remains the core interest of many countries such as those in Africa. Despite the efforts in place to provide adequate, sustainable and modern energy, about 1.4 billion people worldwide do not have access to modern energy carriers (Adeola *et al.,* 2009). Sadly, the majority of the people without access to modern energy subsists in Africa, with a representation of 57% of the world population (UNDP, 2013).

In South Africa, fossil fuel dominates the energy sector, with coal accounting for 89% and crude oil accounting for 22%, thus providing much of the energy consumed in the country (DoE, 2013). In Limpopo Province, the energy carriers do not differ as the energy satisfaction in the province comes from coal and oil. Although, the use of fossil fuel in generating energy brings an overwhelming burden to the environment in the form of greenhouse gas emissions, water contamination, air pollution and ecosystem degradation (DoE, 2013).

Due to the growing awareness of the associated threats of climate change, the rising prices of fossil fuels, the increasing concerns over security of energy supply and increases in electricity prices are the driving factors making renewable energy more competitive in South Africa. After studies of resources assessment, the Limpopo Department of Economic Development, Environment and Tourism (LEDET) has identified biomass and solar as the main renewable resources in the province (DoE, 2015). The DoE has developed a program for attracting private investment into the energy sector. The Renewable Energy Independent Power Procurement program (REIPP) has been designed to contribute towards the national target of 3725 MW of renewable energy and towards socio-economic and environmentally sustainable growth (LEDET, 2013).

To meet energy demands in low- to-middle income households in many developing countries, use of biogas technology is currently being deployed. This technology does not only provide energy but also serves as a good measure to manage health and environmental effects of sloid waste, (Gautam *et al.,* 2009). Limpopo Province like many other South Africa provinces, has seen limited growth in the dissemination of biogas technology due to awareness and perception of the technology. Despite the long history of biogas in South Africa, the country has witnessed poor growth of installed domestic biogas digesters, hence the initiation of this study.

4.2 Households Energy Sources and Utilisation in Limpopo Province

The energy sector is central to South Africa's economy due to its reliance on energy-intensive, large-scale coal mining activities. Limited oil and natural gas reserves are present in the country; thus, the nation relies and uses large deposits of coal to meet most of the energy required, which is principally in the power sector. In 2013, less than 1% of the energy consumed was from renewable sources; 3% from natural gas; 22% from oil while 74% of the total consumed energy was primarily from coal and more than half was consumed in the electricity sector (IEA, 2014). In 2017, South Africa was rated among the ten top producers of coal in the world (World Atlas, 2017). This is due to its dependence on coal: the country is also considered one of the continent's principal emitter of carbon dioxide, accounting for about 40% and placing the country as the 13th major emitter of carbon dioxide in the world (IEA, 2014). Notwithstanding the energy resources endowed in the country, there has been an energy shortage in the country, which led to the energy crisis of 2008, which still persists till date (World Bank, 2016).

A survey by the Department on Energy (2013), with the aim of gathering information related to energy behaviour and perceptions in South Africa households, indicated that there are significant differences between non-electrified and electrified households in Limpopo Province. To meet the basic energy needs, households employed an array of energy sources. Electrified households reported that they use electricity for heating, lighting or cooking. Even so, it is clear that other sources of energy, such as paraffin, fuelwood, gas and candle, are relied upon by at least a fifth of all the surveyed households with electricity. On the other hand, non-electrified households, in the absence of domestic connection primarily rely on fuelwood, candles, with additional households reporting using gas and coal. The use of renewable energy, such as solar was reported by a tenth of the electrified and non-electrified households surveyed. A major factor that continues to play a significant role in domestic energy use is socio-economic differences. The use of paraffin, candles, and fuelwood was present in more than 70% of the households in the low-income bracket, while near-universal access was almost recorded in the medium to high-income households.

Cooking is one of the utmost energy intensive application in the households of Limpopo Province. Unsurprisingly, geographic variation indicated that Limpopo and Eastern Cape

Province households have a lower share of electricity used for cooking purposes, which is less below the national average. Although, most households in the country rely on fuelwood as the second main source of energy for cooking, somewhat atypical is the case of Limpopo Province, where 44% (representing two-fifths of the households) use fuelwood as their main source of energy for cooking compared to 49% of the households using electricity for cooking. Marginal share were reported for households using coal, solar electricity, gas and paraffin. In non-electrified households, paraffin and fuelwood dominate as the source of energy for cooking purposes, at 38% and 54%, respectively. However, a small fraction of coal, gas, solar electricity and electricity from generators were recorded in small percentages of households as their primary sources of energy for their cooking needs. With the increases in paraffin prices, the findings are not too surprising, as fuelwood is an all-possibility compensation for the higher paraffin prices. However, the decrease in paraffin use is positive. However, the increase in the use of fuelwood remains a great concern. Most of the non-electrified households are found in the formal homelands like Limpopo Province.

Domestic space heating is another intensive energy application in the households. In total, 60% or three-fifth of the households use it as an energy source to keep warm and heat spaces. Examination by electrification as the main source for space heating in electrified households indicated that 45% rely primarily on electricity, with a minority reporting paraffin, fuelwood and other sources of energy, at 4%; 7% and 5%, respectively. In non-electrified households in the province's households, fuelwood is primarily relied upon for space heating, accounting for 29%, while paraffin has a share of 11%, with other sources that consist mainly of coal stands at 5%.

In respect to water heating for bathing purposes, the most common electrical appliance used by electrified households in the province for water heating purposes is an electric geyser at 31%.other appliances are the electric kettle at 23% or a combination of electric stove and kettle at 7%. Conversely, in non-electrified households that rely on a single energy source for water heating, fuelwood exclusively accounts for 46%; about a quarter of the households also exclusively uses paraffin, which stands at 27% and 16% of the non-electrified households use a combination of paraffin and fuelwood. The findings from the survey contend that there is a barrier in the province, which is hindering the switch to electricity as a preferred method for water heating for bathing purpose.

In terms of energy preferences and choice for heating water, other than for bathing purposes, the survey indicated that 93% of the households in the province, on average, depend on a single source of energy, while a small share of 5% is characterised by multiple sources. In electrified households, the use of electrical appliances for water heating, other than for bathing purposes, stands at 83%, while in non-electrified households, fuelwood exclusively accounts for 52% for the households, followed by paraffin, which is used by a further 38% of the households.

4.3 Challenges in disseminating the adoption of biogas technology

The biogas challenges faced by several developing countries including South Africa are numerous. These have hindered the general dissemination of renewable energy technologies and biogas in particular. The rate of biogas technology dissemination is low in households, despite its potential, thus making the share of biogas technology in the energy mix very insignificant in many households, where it is supposed to play an alternative option in fuel substituting. In Limpopo Province, the challenges faced by the technology include the following:

4.3.1 Water and feedstock availability

In Sub-Saharan Africa, one site-specific issue that has limited the scope of biogas technology is the availability of water and organic materials (feedstock) that should serve to ensure effective operation of biogas technology. Eshete *et al.,* (2006), suggest in their findings in Ethiopia that sources of water should be a walking distance of between 20-30 mins from the household. Even in the circumstances where households own a satisfactory number of livestock, the system grazing nature, free grazing, semi-nomadic to nomadic have created problems in many parts of Sub-Sahara Africa in gathering feedstock to feed the digesters (Winrock International, 2007). In Limpopo Province, poor supply of water has been reported as hindrance in the operation of biogas plants. For example, where there is adequate water supply, there is widespread adoption of the technology; mostly if the source of water is a short distance from the household or the supply is not altered by seasonal variation. Water shortages limit biogas operations as it is required in the mixture of the substrate before being fed into the digester (Eshete *et al.,* 2006).

Steady access to sufficient water supply is only available to small a percentage of the African region (Surendra *et al.,* 2014) Sub-Sahara countries such as South Africa are considered as water-scare countries due to its climate aridity. Most parts of the country are characterised by pro-long periods of drought between the rainy seasons, with rainfall less than the world average, coupled with uneven distribution throughout the country (DWAF, 2007). The South African Government in 2001 approved a free basic water policy to deliver at least 6 000 L of safe water to each household per month for a household of about eight persons (DWAF, 2007). Since the commencement of the free basic water policy, the household percentage with access to tap or piped water in their dwellings, on-site and off-site (communal taps), has improved from around 85% in 2002 to 70% in 2012. Nonetheless, general access to water by households is only improving by 4.2%, as most households still have to fetch water from dams, rivers, water pools, streams, springs and stagnant water (Statistics South Africa, 2013b).

4.3.2 Dearth of private sector participation

The private sector has key roles to play in the promotion of renewable energy, such as in biogas technology in order to make it market-oriented and commercially sustainable. Renewable energy policies should be drawn in such a way that they attract participation of private organisations (Ghimire, 2013). For instance, in 2009, Nepal had more than 30 private organisations, which were actively involved in the biogas sector. However, only eight organisations were able to install a little over 500 biogas digesters, due to the unfavourable renewable policies (Gautam *et al.,* 2009). In Limpopo Province, there is only one established biogas actor (Mpfuneko Biogas project), a Non-Governmental Organisation (NGO) that supports the development, and dissemination of biogas projects in the Greater Giyani Municipality of the province.

4.3.3 Lack of technical availability

In most Africa countries, lack of technical assistance is often cited as a reason for the impeding adoption of biogas technology. Technical knowledge ranges from the construction, maintenance and operation of the technology (Parawira, 2009; Amigun *et al.,* 2011). Usually, where biogas digesters have been installed, the problems arises of reactors being of poor quality in the installed units are cited. Poor operations and maintenance ability of users have also led to poor performance of the digester, sometimes leading to the abandonment of the technology. In some cases, the demonstration plants have failed, which served to deter instead of enhancing the adoption of the technology (Parawira, 2009; Amigun *et al.,* 2011). To promote the implementation and proper use of biogas technology, it is imperative to initiate long-term, biogas technology capacity-building programmes as well as training and execution of scientific work in the field through applicable research (Parawira, 2009). Biogas technology and implementation techniques can be introduced in the curriculum of most technical and engineering courses offered in universities, technical and vocational training colleges.

4.3.4 Cost associated with installing biogas digester

One frequently cited factor limiting the development of biogas technology is financial constraints. In Ghana, for example, according to Arthur *et al.,* (2011), the findings indicated that, although the technology can solve some of the environmental and energy challenges faced in the urban and rural parts of the country, as well as industrial organisations, the technology requires a high initial cost of investment. The main obstacle hindering the use of the technology by the rural cattle farmers is their inability to cover the full cost associated with installing the technology. Bensah and Brew-Hammond (2010) stressed that the principal hindrance to biogas technology expansion in Ghana is the cost of building the digesters, which most farmers have complained about. Financial incentives in the form of subsidies, loans, and credits are among the recommendations reported for the successful dissemination of the technology. In South Africa, the average cost of mounting a smallholding biogas digester of 6 m^3 ranges from R 15 000 to R40 000 (Tiepelt, 2015), whereas a 10 m^3 costs not less than R80 000 (Mukumba *et al.,* 2016).

Therefore, subsidies can enhance the relative advantages and speed up the adoption of biogas technology by those entities who would not have ordinarily adopted the technology (Rogers, 2003). Furthermore, some technologies have socially desired features; thus, adopting such technology is not only beneficial to the owner but to the society too. In many Organisation for Economic Cooperation and Development (OECD) countries, companies and individual households can seek government subsidies if they adopt technology that is socially desirable. Even if the investment cost surpasses private benefits but is lower than social benefits, government provides subsidies to enhance the adoption of technologies that provides social benefits (Aalbers *et al.,* 2007). Furthermore, the size of the subsidies significantly influences the rates of adoption. In China, for instance, there was a time when interest in adopting biogas technology fading away just after the government reduced subsidies to one-third of the investment cost from two-thirds (Rajendran *et al.,* 2012). In Nepal, it was revealed that without subsidies, most of the Nepalese farmers would have not have been able to adopt the technology, due to their financial constraints (Bajgain 2005). Although, providing subsides may not positively increase the intended adoption rate of the technology. Individuals who adopt the technology for the sake of obtaining subsidies may be less enthusiastic to keep using the technology (Rogers, 2003).

Additionally, households consider a variety of issues in their decisions to either to adopt or reject using modern energy technologies. Among other considerations, cost is of critical importance affecting the final decision by the consumer. Most consumers would prefer a modern technology with low initial costs compared to one that minimised cost of operations but ran over an extended period. Thus, creating a balance between initial costs alongside operation cost is important. In countries with low income, where individuals lack access to credit/ and or cash, widespread preference is often associated with low initial cost (Reddy and Painuly, 2004). Gebreegziabher (2007), in supporting the argument, stated that in

Ethiopia, high initial cost of investment remains a major obstacle in the prevalent dissemination of biogas technology.

4.3.5 Lack of biogas technology awareness

Another important factor which act as a constraint to the adoption and dissemination of biogas technology is the awareness of the technology (Mukumba *et al.,* 2016). In Ghana, for example, lack of awareness about biogas technology was mentioned as one of the barriers in adopting the technology. Some cultural viewpoints such as stigmatizing the utilisation of human excreta or even cow dung as substrate to biogas digesters, has the potentiality of discouraging its dissemination (Arthur *et al.,* 2011). Thus, stories of successes and failures of previous biogas installations can also aid in promoting or constraining the dissemination of the technology. According to Gitonga (1997), where an installed biogas digester performed well, word of mouth from the satisfied user will encourage other potential users to own the technology. In instances where the digester fails, it will create a negative dissemination impact on the technology; thus, discouraging potential adopters in the process. In Africa, success stories of biogas demonstration plants are relatively low. Many reasons are outlined for their failure. These include absence of energy focused policy, poor design, poor construction and material used, lack of maintenance from the owner, lack of project monitoring and follow-ups and poor ownership attitude and responsibility (Arthur *et al.,* 2011).

In addition, households evaluate the different attributes of a modern energy carrier in their adoption decisions. Roger (2003) identifies five attributes that can accelerate or impede the adoption rate of the technology. These attributes are relative advantages, trialability, observability complexity and compatibility. In the relative advantage of a modern energy carrier, the technology is evaluated in economic terms; according to its social status, satisfaction and convenience. A technology that is easily tried and experimented for its appropriateness with observable results to others is expected to be rapidly adopted than others. Furthermore, a compatible technology to existing cultural norms, values and experiences of a community has a better chance of adoption compared to any technology against such values and norms. In addition, a technology that is easy in understating and utilising is likely to be adopted quicker than those that require new skills, knowledge and understanding. According to Taherdoost (2018), in the traditional adoption technology model, primarily, a consumer's adoption is determined by the 'perceived ease of use' and the 'perceived usefulness/benefits' of the technology. Therefore, in the process of making and informed decision to either reject or accept the new technology, the consumers weigh the option of the technology if it is easy to utilise (perceived ease of use) and if one's productivity will improve (perceived usefulness/benefits).

4.4 Research Methodology

The collected data was based on a field survey elicited from self-administered questionnaires and interviews. The data was analysed using Spearman Rank non-parametric test and chi square. The results are presented in simple tables, bar and pie graphs.

4.5 Results and discussion

4.5.1 Awareness and perceptions of biogas adoption

Technology adoption is influenced by the awareness and perceptions of usefulness of such technology. Thus, measuring the level of biogas awareness and perceptions by the users and non-users in the province, provides an insight into ascertaining the future of the technology in respect to adopting and utilising biogas at household level.

4.5.1.1 Biogas technology awareness

The study findings as presented in Figure 4.1 indicated that 22% of the respondents acknowledged that they have at least heard about the technology. This implies that few households in the Limpopo Province are aware about the existence of the technology. This can be attributed to the few biogas projects within their locality. Awareness of the technology’s existence in the study area, however does not imply awareness of the technology itself. Awareness of biogas technology involves households getting detailed information about the technology; from the functionality, financial implication and advantages, before it can influence their decision to adopt the technology. This further shows that 78% of the households have no relative idea about biogas technology.

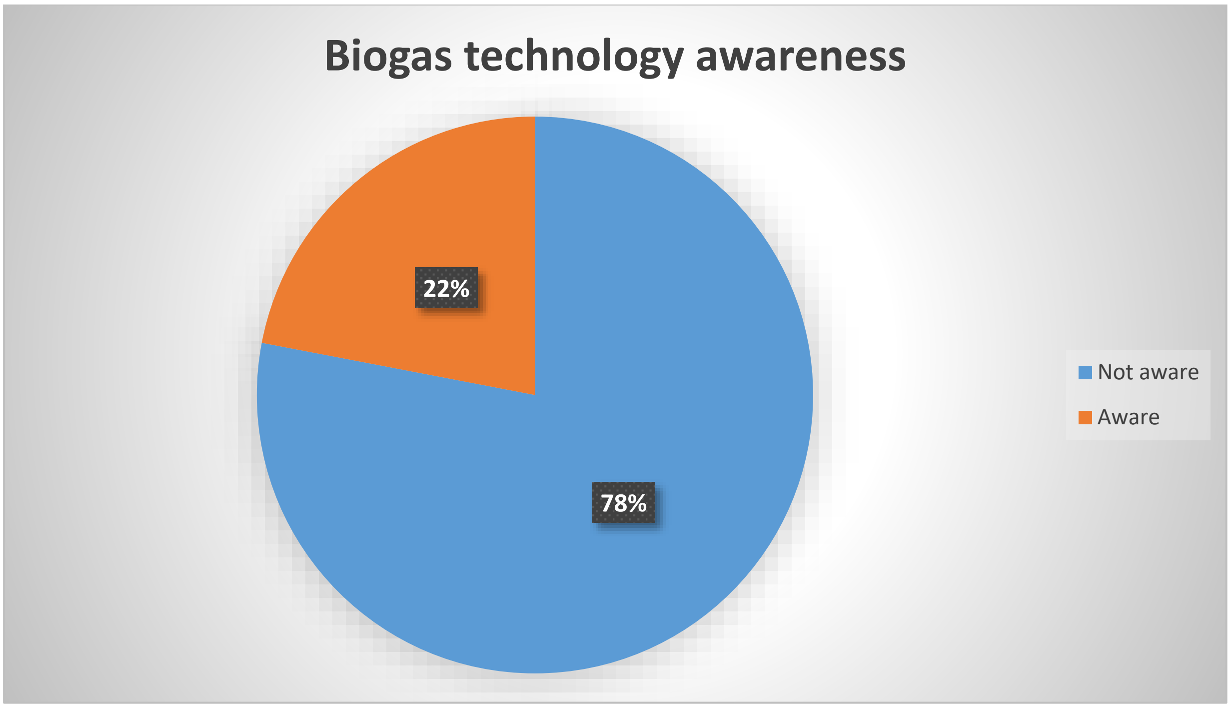


Figure 4.1: Biogas technology awareness survey in the study area (Source: Field survey, 2018).

Technology awareness and perceptions are also disseminated via information channels. From the study, the identified channels of information that have helped in sensitizing the households about the significances, advantages and efficiencies of biogas technology in the province include those from neighbours with installed digesters, at 52%, and NGOs at 38%, which served as the main sources of information pertaining to the technology. Others include 7% from government departments/agencies and 3% from media publications. This indicates that the role of the media in disseminating the technology is very low. Furthermore, government departments and agencies are not playing a significant role either. This can be improved through adequate education and dissemination, partcilarltly in the rural areas, so that the social, economic and environmental benefits of the technology can be appreciated as against the continues use of fuelwood, which has detremental effects on their health and wellbeing (Mukumba *et al.,* 2016).

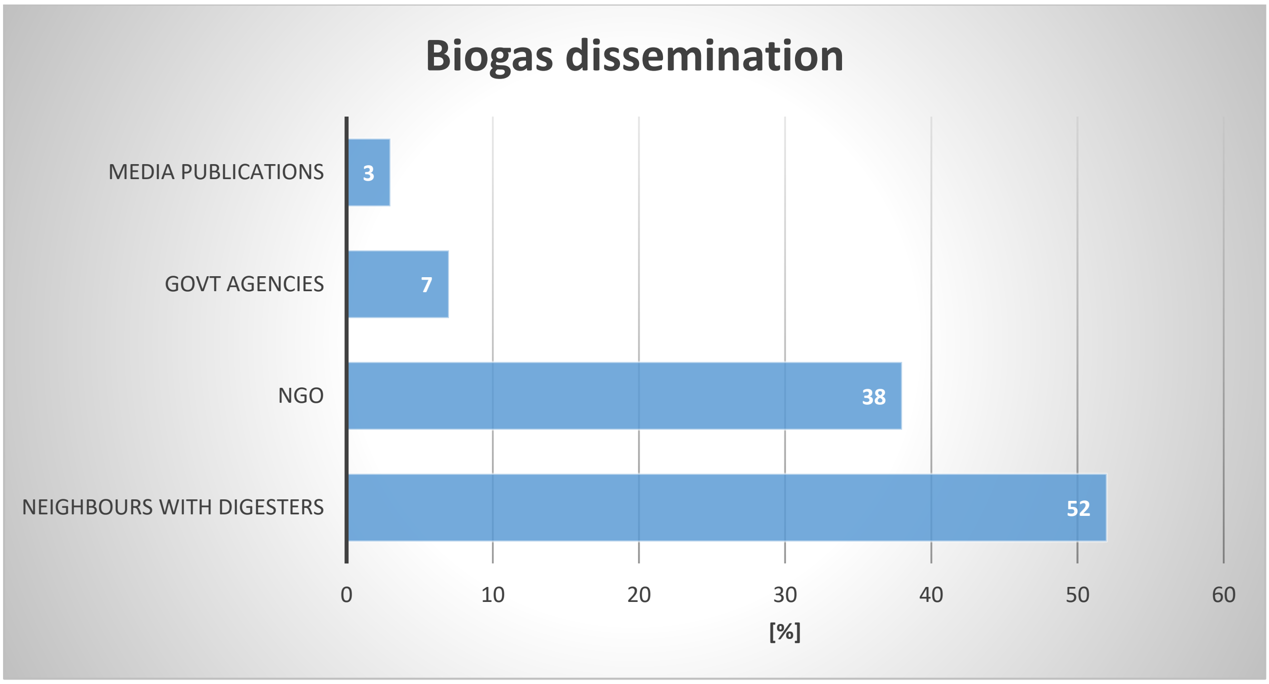


Figure 4.2: Biogas dissemination in the study area (Source: Field survey, 2018).

Figure 4.3: A household member preparing to feed a digester with cow dung (Source: Field survey, 2018). Permission to use by respondent.

4.5.1.2 Biogas technology perceptions in households

From the field survey, the data obtained clearly shows that there was a prevalent perception that biogas technology can solve most of the issues faced by households. The responses raised on the perceptions of the technology indicated that in households with biogas digesters, 91% agreed that biogas can help solve the problem of fuelwood for cooking, as against 87% from the non-users. Regarding using the slurry from biogas to improve soil fertility, 88% of the users agreed, while 86% from the non-users also concurred. Using biogas technology as a method to manage waste in order to improve environmental hygiene was at 89% from the users believes. They believed that it is a good management method compared to 88% from the non-users category. In the province, as part of their energy mix, most households still rely on fuelwood, which is harvested from the forest, thereby creating room for degradation. This can eventually lead to deforestation. With the use of biogas technology, 90% of the households using the technology have confidence that it can help reduce the rate of degradation and deforestation, while 75% from the non-users concurred. From the field data, women carry between 25 to 40 kg headload of fuelwood over a distance of 2km. From the users and non-users, 96% from both clusters indicated that the use of biogas technology could help reduce the drudgery faced by women. On fuel consumption, compared to other cooking devices, 95% from the households using the technology agree d while from the non-users, 91% have the confidence that the technology will consume less fuel. On the general benefits of the technology, 89% from the users agreed that the benefits are worthy, while 82% from the non-users have confidence in the benefits of the technology.

Further, the outcomes of the respondents were ranked and tested using Spearman Rank Correlation Coefficient, to determine if there is any significant correlation between the data from the users and non-users. The Spearman Rank results at $P < 0.05$, with a calculated value of 0.68, indicated that there is a positive and strong correlation in the perception of biogas technology among the users and non-users in the province. In essence, the more and better perception households have on biogas technology, the better the chance of adopting the technology.

Table 4.1: Biogas technology perceptions between user and non-user in the province

Statement	Users	Non-user
Biogas can help solve the problem of fuelwood for cooking.	91%	87%
Biogas technology can help to improve soil fertility.	88%	86%
Biogas technology can improve hygiene due to the use of waste.	89%	88%
Biogas technology can reduce the rate of forest degradation and deforestation.	90%	75%
Biogas can relieve women's workload and save time used for fuelwood collection.	96%	96%
Biogas technology consumes less fuel than other conventional cooking devices	95%	91%
Generally benefits of Biogas technology over-weighs limitation/weakness.	89%	82%

Source: Field survey, 2018.

4.5.2 Cost and biogas digester

In the absence of subsidies, loans and credits, the uptake of the technology at household level can only be driven by income earned by the household. Consequently, the higher the income earned by households, the more they will be expected to adopt the technology compared to households earning less income. Thus, income is expected to influence the adoption of the technology. This is because households consider a range of issues in their choice to either adopt or reject modern energy carriers. In the study area, income earned is low compared to other provinces in the country, due to the high unemployment rate that has characterised much part of the province. From the field survey results, only 15 households from the technology users' category, representing 20.8%, earn above R3 501, with 18 households, representing 14% earning above the same amount. Most of the users and non-users of the technology are in the income bracket of R501 to R3 500. As noted, the average cost of installing a smallholding biogas digester ranges from R15 000 to R 40 000 and R80 000 (Tiepelt, 2015; Mukumba *et al.,* 2016).

Table 4.2: Income bracket of surveyed households of biogas users and non-users in the study area.

Income	users	Non-users	Total
R0-500	**08** (11.1)	**16** (12.5)	**24** (12.0)
R501-1000	**12** (16.7)	**31** (24.2)	**43** (21.5)
R1001-1500	**17** (23.6)	**33** (25.5)	**50** (25.0)
R1501-3500	**20** (27.8)	**30** (23.5)	**50** (25.0)
R3501+	**15** (20.8)	**18** (14.0)	**33** (16.5)
Total	**72** (100)	**128** (100)	**200** (100)

(Bolded figures represent frequency and brackets for percentage frequency). Source: Field survey, 2018.

Using the Pearson's Chi Square test, income earned by households was cross tabulated against the cost of building a digester, to determine the significant relationship between both variables. The result, at $p < 0.05$, indicated that there is a statistical significant relationship between the income earned and the cost of installing a biogas digester. This implies that income earned by households in the province affects the adoption of the technology. As noted, the low income earned is a factor of the socio-economic challenges being faced in the province.

Table 4.3: Pearson Chi-Square test results for income and costs of installing biogas digester.

	Value	df	Asymp. Sig. (2-sided)
Pearson's Chi-Square	43.251[a]	3	.000
Likelihood Ratio	41.598	3	.000
Linear-by-Linear Association	19.917	1	.000
N of Valid Cases	200		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 8.91.

4.5.3 Water and feedstock availability

Water is one of the critical requirements for the proper functioning of biogas technology. An equal amount of water is mixed with the required substrate before being fed into the digester. Findings from the survey indicated that households have access to water within a walking distance of 20-30 mins from the household but are faced with acute, irregular supply and shortages that have marred most parts of the province.

Availability of feedstock is another requirement that is unavoidable in the operation of biogas technology. Cow dung is considered as the major feedstock in the study area. The findings, as portrayed in Table 4.4, revealed that 93% of the households use the technology in the province own livestock, as against 7% that do not own livestock but source for it either by buying or obtaining from neighbours who own livestock. Furthermore, 79.7% of households without the technology own livestock, while 20.3% do not own livestock.

Table 4.4: Livestock ownership by households in the study area.

	Users	Non-users	Total
Livestock ownership	**67** (93)	**102** (79.7)	**169** (84.5)
Do not own livestock	**5** (7.0)	**26** (20.3)	**31** (15.5)
Total	**72** (100)	**128** (100)	**200** (100)

(Bolded faces represents frequency and brackets for percentage frequency). Source: Field survey, 2018.

4.5.4 Technical availability and assistance

Technical availability is an integral determinant in the adoption of biogas technology at household level in the province. Available technical availability and assistance are deemed as a good support for the dissemination, adoption and utilisation of the technology. The study reported that unreliable and unavailable technical services were a common problem reported by households with installed digesters. In addition, households with interest about the technology shared the same sentiment. The question of technical support was directed to households with installed digesters and the findings show that 96% of the households complained about technical assistance of any sort. Technical issues faced by some households included blocked pipes as well as cracked and leaking digesters, which limit the use of the technology and sometimes leads to total abandonment when they cannot access any technical assistance.

4.6 Summary

This chapter has provided first-hand evidence on the awareness and perceptions of biogas technology in the province in understanding the challenges in disseminating the technology. The awareness was measured based on the dissemination, functionality, and cost of biogas digesters among the sampled households. The perceptions of the technology was measured based on households insights regarding the role of biogas in fuel crisis, soil fertility, livestock management, burden of fuelwood collection, livestock ownership, water and feedstock availability as well as technical availability and assistance. In order to understand the in-depth the awareness and perceptions of the households, the variables were further tested using a spearman rank correlation co-efficient and chi square test to ascertain the significance relationships between the variables. The next chapter emphases the correlating factors influencing households adoption and utilisation of the technology in the Limpopo Province.

CHAPTER 5

CORRELATING THE FACTORS INFLUENCING HOUSEHOLD DECISIONS ON ADOPTION AND UTILISATION OF BIOGAS TECHNOLOGY IN LIMPOPO PROVINCE

5.1 Introduction

Energy is an indispensable contribution that defines the pace and status of a country's development. For most developing countries, including South Africa, the services and provision of sustainable, adequate, reliable and affordable energy have been a continuous and serious task for most. In developed and developing nations, in order to achieve inclusive and sustained growth, energy plays a central role, as more current studies have shown. This is because there is a strong correlation between energy consumption and development (Negro *et al.,* 2012). Energy issues do not only affect economic growth but also have a profound impact on the social, environmental and human aspects (Amigun *et al.,* 2011). Furthermore, access to improved energy services plays a prominent role in a country's health improvement, promotion of economic growth, poverty reduction, competitiveness and gender balance (Amigun *et al.,* 2008).

To meet her energy demands, South Africa, like most other countries, depends largely on fossil fuel. However, increasingly, due to environmental and ecological consequences associated with its uses, fossil fuel has, become an unstainable energy source (Karekezi, 2002). Owing to the high coal dependence in the country, the carbon dioxide emissions per capita (metric tons) stand at 9.1, compared to other Sub-Saharan Africa countries, with an equivalent of 0.8 and the world average of 5.4 (World Bank, 2015). Problems associated with fossil fuels being un-sustainable have led to increased awareness and widespread research into the availability and development of renewable energy sources, which have been recognised as an alternative in addressing the difficulties of fossil fuels (Karekezi, 2002). Evidence from the literature reveals that a substantial number of countries has overcome the energy shortages gap through renewable energy resources (Awan and Khan, 2014).

South Africa are endowed with diverse sources of energy, which include hydro, wind, solar biomass, geothermal and fossil fuels. These can be broadly classified into three categories; namely, traditional, commercial and alternative sources. The traditional sources include fuelwood, agricultural residues and paraffin (kerosene), and are used mainly for domestic purposes. Commercial sources include electricity and petroleum products. Alternative energy sources are the renewables and consist of the likes of biogas. Through the White Paper Policy on Renewable Energy, the South African government has taken a new trajectory on sustainable development and growth, where the renewables are expected to contribute 17

800 MW of energy, in order to lessen its reliance on coal and also lower the greenhouse gas emission. The government believes that renewable resources play an important role in advancing and transforming of the energy sector, as well as ensuring social equity. It is expected that renewable energy will contribute towards the creation of green jobs in the economy, diversification of the country's energy mix and providing access to modern energy services by the year 2025 (DoE, 2015).

The broadening energy gap already existing in the country can be reduced through biogas technology, by providing energy for heating and cooking mainly in the rural parts of the country, where the mission of distributing grid electricity is challenging, and often times unattainable financially and technically (Charters, 2001). Furthermore, biogas technology provides a clean and renewable energy form that can supplement other conventional energy sources, by reducing emissions of greenhouse gases and enhance the production of bio-fertiliser. If proper management practices are followed, biogas technology can be a clean source of energy for augmenting domestic energy to households, increasing agricultural productivity and improving the environmental well-being of the community. This, perhaps, signifies a great overlook for the advancement of the technology. In South Africa, biogas technology has a long history, as the first experimental digester, which was introduced roughly six decades ago (Tiepelt, 2015). Based on the population of the current cattle of 630 000 in the country, it theoretically places the potential of biogas technology in total manure production at an annual methane production of 93 492 000 m^3/a, and annual thermal energy production at 420 714 MWh/a. The annual electricity production at 327 222 MWh/a and 1 764 000 Mg/a (GTZ, 2016).

In order to benefit from the aforementioned capabilities of biogas technology, the South African government, in its agenda, adopted the top-down approach in providing biogas digesters for households in rural areas of the country, through the promotion of pro-poor energy alternatives. However, regardless of the comparatively high potential endowed in the country for the expansion of the technology, the dissemination and development level of the technology remains very low (Tiepelt, 2015). Furthermore, the number of installed biogas digesters countrywide remains in the region of 700 (SABIA, 2013). Notwithstanding this effort, the technology has not produced the anticipated results and the reasons, by and large, remain unclear. A few biogas-related studies exist in South Africa. However, they have not sufficiently dwelled on the factors influencing the adoption and utilisation of the technology. Household decisions vary in adopting a technology and it is based on the roles played by endowments of resource, socio-cultural, economic, environmental and technical factors. For successful acceptance of any technology, the intervention policy, designs, region specific and information are essential (Berkele and Verburg, 2011).

5.2 Research Methodology

The elicited data from the self-administered questionnaire were analysed using the logistic regression model, and the results displayed in simple tables.

5.3 Variables explaining biogas technology adoption

According to Rogers (2003), technology adoption is an order of steps that varies from knowing about the intended technology, gathering information, developing interest, evaluating the technology and its characteristics and consequently taking a decision to either adopt or reject the technology outright. In the present case study, the aim was not only to understand the adoption processes but also to untie the influencing fundamental factors leading households to either use or not use the technology. Globally, many studies at household levels have been piloted on the adoption and diffusion of biogas technology in promoting it as a feasible source of renewable energy. The decision, however, involving resource allocation to a particular technology, includes the thoughts of many alternatives and reasons (Anderson, 2002). In Sub-Saharan African countries, widespread socio-economic hindrances undermining the adoption of the technology and factors that can promote the technology were explored and examined by Mwirigi *et al.,* (2014). The level of technology adoption in many countries has also been studied.

For example, in Kenya, the hurdles of socio-economic and sustainability impacts in adopting the technology were studied. The study showed that a farmer's status in terms of socio-economic standing, implicitly determines his/her decision in adopting the technology, but not the sustainability of the already installed biogas digesters (Mwirigi *et al.,* 2009). In Uganda, the size of the household digesters, cost of traditional fuels, the number of cattle owned and household income, were factors that influenced the technology adoption (Walekhwa *et al.,* 2009). Government support and other related household factors, such as the age of the household head, level of income and household size, were the influencing factors in farmers' decision to adopt the technology. In Bangladesh, the factors influencing the adoption decision of the technology included the number of cattle owned, educational level, income level and gender of the head of households (Kabir *et al.,* 2013). The key findings in by Inayatullah and Waqar, (2018) indicated that the factors influencing the adoption biogas technology in Pakistan include daily electricity shortfalls, the level of education, female drudgery and awareness of the technology as well as its effect on children's education. Also included in the findings in Pakistan was awareness about the technology as well as the socio-economic status of the respondents (Abbas *et al.,* 2017). Amigun and von Blottnitz, (2010) studied cost analysis as a factor in the adoption of biogas technology.

The anticipated results of a household's decision to adopt a technology are outcomes of numerous characteristics, which are vital in the adoption processes. In the current study, adoption is defined as the acceptance of biogas technology and utilisation refers to the actual using of the technology in meeting household needs. Related studies also revealed several factors affecting the process of technology adoption. The main factors in the adoption of biogas technology included demographic, social, institutional, technical economic and environmental. Significantly, over space and time, the comparative factors differ from place to place, due to economic, social and environmental settings (Bekele and Drake, 2003). Descriptive variables are measured in the adoption processes and perhaps this is because the perceptions that households reflect on a variety of concerns, separate from the socio-economic factors. From the literature, various studies have agreed that personal, physical, institutional, social and economic factors are noteworthy determinants of the course of adoption. Explanatory and description variables, as well as the meanings considered for adoption in the study, are presented in the research methodology in chapter three.

The household heads age can also influence (positively or negatively) regarding decision-making whether to adopt biogas technology or not. According to Nhembo (2003), old age is linked with conservatism and may sometimes negatively influence their readiness to adopt new technologies. Often, old people are not prepared to try-out new concepts because they are considered more risk averse. Older people however, are occasionally regarded as having extra resources, with a higher economic standing that it can assist them in engaging in capital-intensive technologies than the younger peers. On the other hand, younger heads of household are deemed to have long planning horizons and are therefore more innovative and perceived to take related risks with new technologies. Accordingly, there are some innovation and technology, where younger household heads stand a better opportunity of adopting than older household heads. Improved creativity and capacity for greater access to information are also often connected with the educational level a person has achieved. Therefore, educated heads of household are expected to be more cognisant of new technology; better informed and alert environmentally about the adversative consequences to the environment because of consuming fossil fuel. On the grounds of environmental awareness, it is positively assumed that persons who are more educated will go for a cleaner energy source, such as biogas, as opposed to their counterparts who are less educated. Thus, knowledge reduces uncertainty and therefore could boost the chances of adopting a technology.

The gender of the household head can also positively or negatively motivate the adoption of biogas technology, subject to the gender tasks performed. The responsibilities could be in the form of performed tasks between women and men in energy supply. According to Karekezi (2002), in most rural households, women control the domestic supply of energy, as it is considered as one of their primary responsibilities. The responsibilities also include food preparation, fuelwood collection, waste disposal management, and general home maintenance. Compared to male-headed households, it is anticipated that households headed by women would embrace biogas technology easier as it can lessen the burden of their workload. Nonetheless, as in many other countries such as South Africa, there is a hierarchical relationship, with most family settings taking the form of male dominance and women subordination. Decision-making, access, ownership and control concerning household investments and productive resources that could directly influence the adoption of biogas technology are male dominated. Household size is another factor likely to negatively or positively inspire household decision on adopting a technology such as biogas. A large family often, means having more support for the routine operation and maintenance of a technology such as biogas. Therefore, a larger family is considered as having a better prospect of adopting biogas technology. On the other hand, a larger household could mean exerting a substantial dependency burden on the family's scarce means, to the level that there could hardly be any reserves left to invest in a new technology such as biogas. In circumstances like these, the size of household could negatively affect decisions about biogas technology. According to the conclusions by Kebede *et al.,* (1999), if family relations are seen as extra sources of assistances, then farmers may try new practices. However, if they are viewed as dependents, then the reverse may true.

The income earned by households determines the uptake of a technology. Hence, higher income levels at households are expected to readily ease the adoption of a new technology, such as biogas technology compared to households with lower levels of income. Household income is therefore expected to carry a positive symbol, as it is assumed that the adoption of biogas technology increases with household levels of income. In rural South African households, the substrate for biogas digesters is primarily cow dung. Thus, the promotion of the technology in these rural areas targets households with three or more cattle. Hence, the number of cattle owned per household in rural areas is a central issue in the adoption of the technology because it guarantees the provision of dung, which is the main substrate for the operation of the digesters. Thus, used as a pointer, the number of cattle owned is anticipated to positively or negatively influence the adoption of biogas technology. The production of crops is another significant factor that can influence households' decision in adopting or rejecting biogas technology. Households that are involved in subsistence crop production are likely to positively adopt the technology, as the substrate from the digester can serve as a good fertiliser option to nurture their crops and increase production. Thus, the households' involvement in subsistence farming is anticipated to influence adoption of the technology. In the rural households of South Africa, awareness is another key factor considered that can negatively or positively influence biogas technology adoption. Regarding the technology, therefore, sufficient knowledge can positively influence the acceptance of the technology (Parawira *et al.,* 2012; Sardianou and Genoudi, 2013). Technical availability is also expected to positively influence the adoption of the technology in South Africa rural households. Technical support in the form of skilled and un-skilled workforce is essential for the successful operation and maintenance of biogas technology and therefore influences adoption of the technology.

The source and distance to fuelwood collection is expected to negatively or positively sway the adoption of biogas technology. Fuelwood collection source and distance increase the opportunity cost of collecting fuelwood (Guta, 2014). Hence, the farther the distance to the fuelwood collection source from home, the more positively or negatively it will influence the adoption of biogas technology. The availability and distance of water sources can also influence the adoption of biogas technology. For daily feeding of the digester, the source of water needs to be within 20-30 minutes' walking distance from home (Eshete *et al.,* 2006). A dependable and available source of water is also a significant factor in the adoption of the technology, as these could negatively or positively influence the choice of the household in adopting the technology. Initial capital investment is also required in biogas technology, given the cost associated with the technology. For low-income groups in rural households, having access to subsidies, loans and credit is necessary, as financial support is supposed to encourage and positively affect on the adoption of the technology. Thus, the availability of credit, subsidies and loans are expected to have a positive association with biogas technology adoption.

5.4 Results and discussion

5.4.1 Profiles of household samples

Analysed and computed results of the considered descriptive data and variables as factors influencing biogas technology in the study are presented in Table 5.1. From the sample of 200 households, comprising biogas users and non-users, the analysis shows that 39.4% of the households were female-headed, while 60.6% were male-headed. Additionally, the monthly income analysis indicated that 85.5% earn less than R3501 per month, while 15% and 14%

have a monthly income of more than R3501 among the users and non-users of the technology respectively. The results also reveal limited access to credit, subsidies and loan for both users and non-users. Furthermore, there were similarities among users and non-users of the technology in respect to fuelwood distance and source, as well as technical availability, household size, biogas awareness, water source and availability and number of cattle owned. On average, however, biogas users were older and had attained more education than their counterparts of non-users of the technology.

Table 5.1: Descriptive statistics explaining chosen variables for biogas technology adoption in Limpopo Province.

Variable	Biogas-users (N = 72)	Non-biogas users (N = 128)	Total Sample (N = 200)
AGE	52.89	47.09	50**
EDUL	14.72	12.48	13.6**
GENDR (%)			
Male	53	68.2	60.6
Female	47	31.8	39.4
HHSZ	6.39	8.43	7.41**
INCOME (%)			
R0-500	8.6	7.4	8
R501-1000	14.8	15.9	15.35
R1001-1500	22	20.7	21.35
R1501-3500	39.6	42	40.8
R3501+	15	14	14.5
CATTLE	4.82	4.02	4.42**
CROP	143.8	87.2	115.5**
BIOAWA (%)			
Yes	48	54	51
No	52	46	49
TECHAVAB (%)			
Yes	32	24	28
No	68	76	72
FWSD	18.63	20.98	19.8**
WATERASD	6.44	7.25	6.84**
SLC	0.84	0.76	0.8*

***, ** and * indicates statistical significance difference between users and non-users of biogas at $p < 0.01$, $p < 0.05$, and $p < 0.1$ (means difference was checked using t-test).

5.4.2 Reasons for adopting biogas technology at household level in Limpopo Province

The users highlighted several reasons as the motivating factors in the adoption of biogas technology. According to Anderson (2002), decisions regarding the allocation of resources include the assumption of a number of alternatives and motives. The main reason by respondents with installed biogas digester is that the government installed the digesters for free. The Government intended to disseminate the technology, particularly in the former homelands such as in the Limpopo Province, where some of its communities are still faced with shortages of energy from the national grid. Thus, the digesters were installed as demonstration plants by the government, which hoped the citizenry would adopt it, in order to augment their energy demand. The criteria used in identifying deserving households by the government included, among others, the ownership of at least three or more cattle and household's engagement in subsistence crop production. The other factors revealed by participants showed that 92% of the households adopted the technology due to its technical evaluation against other cooking devices, such as paraffin, fuelwood, LPG, electric stove and charcoal. Compared to other cooking devices, the respondents agreed that a biogas stove is more efficient in terms of cooking time and the fuel consumed. Nevertheless, 57% of the respondents indicated that, compared to other cooking devices (electric stove and LPG), biogas is less sophisticated in terms of space, seasonal/ continuous use, weight need and size. The economic evaluation of the technology alongside other cooking devices revealed that only 24% of the respondents concurred that a biogas stove is better off in terms of fuel cost, initial cost and maintenance.

In evaluating the environmental facets of a biogas cooking device against other cooking devices of paraffin, fuelwood, electric stove and charcoal, 96% of the respondents considered the technology to be ahead in terms of reducing the impact on forest, abating air pollution and soil degradation levels. The commercial evaluation household survey on biogas cooking device was also found to be deficient by 88% of the respondents when compared to other associated cooking devices. The dissimilarities were in terms of spares availability and after-sales services. The social evaluation, need for training on how to use the technology, sufficiently managed and improvements in the stove models, as most of the utensil used for cooking (namely, pots) used by these households do not properly fit on the stove, was rated at 22%. However, the technology scored 98% when matched against other cooking devices, in terms of potential to provide employment and that of human drudgery. Behavioural evaluation of the technology, when compared to other cooking devices, revealed that 64% of the respondents have the impression that food prepared on biogas cooking stoves taste better than using other cooking devices. A further 76% agreed that using the technology for cooking purpose helps in keeping the cooking utensils clean, compared to charcoal, fuelwood and paraffin. In respect to ease of operation, 42% agreed that it is easy to operate the technology. The technology aesthetics, compared to other devices, was 38%, as indicated by the respondents, while 44% concurred that they are motivated to buy the technology. In comparing the technology of biogas cooking stove, it scored lowly at 36% against other cooking devices in reverence to exclusivity of dishes to be cooked. Furthermore, 90% of the respondents revealed that biogas only cannot be sustained and hence there is a need for other supplementary cooking devices/stoves.

5.4.3 Correlating factors influencing biogas technology adoption in Limpopo Province

Regarding studies on adoption, if reliable interpretation is to be accomplished, there is a need for caution appraisals using sufficient data and a rigorous theoretical framework. Different objectives and methodologies lead to divergent issues being evaluated and reported, thereby affecting adoption changeover cycle of technology diffusion (Floyd *et al.,* 2003). The analysis results from the logistic regression model revealed that the estimated values and observed data using the model reasonably fitted. Additionally, when measuring the goodness-of-fit of the model, the outcomes indicated that the log's odds of adoption simultaneously correlated with the independent variables. In addition, the model accurately predicted the statistical significance of 92.6% of the total biogas users and 90.5% for non-users from the total sampled households. The Cox and Snell R^2, which is a comparable measure of the goodness-of-fit, was 52.3%, while the Nagelkerke R^2 was 64.80%, which is adequate for supporting the quality of the model. The validation of the goodness-of-fit of the regression model is through the Hosmer and Lemeshow test (χ^2 test). In comparison to the chi-square, the Hosmer and Lemeshow is considered more robust, particularly if the samples are small or continuous co-variates of non-significant values are contained in the model (Garson, 2008). For Kabir and Yegbemey, (2013), when the pseudo R^2 value is more than 15%, the quality of the model is considered robust and not affected. To a satisfactory degree, this showed that the model was fit for the data.

Among the twelve variables in the analysis, the Wald test (χ^2 test) results confirmed that nine of the variables were statistically significant, at ($p < 0.01$) in influencing the adoption of biogas technology in the households (Table 5.1). The variables include age of heads of households, household head's level of education, number of cattle owned, distance to fuelwood source, gender, crop production, credits, loan and subsidies, income, awareness and water availability. These variables were found to have a positive relationship with the adoption of biogas technology. While three variables; namely, distance to fuelwood source, household size and technical availability, were also found to be statistically significant, at $p < 0.05$, although they were associated negatively with the adoption of biogas technology. This indicates that the probability of a household adopting the technology increases with the effects of these variables and vice versa.

Table 5.2: Logistic regression model results for biogas adoption in Limpopo Province.

Variable	Coefficient	Standard error	Wald	Odds ratio
Constant	3.051**	1.548	6.825	21.35
AGE	0.179	0.161	12.169	1.891
EDUL	0.084*	0.47	3.079	1.920
GENDR	0.727**	0.460	2.134	1.610
HHZ	-0.017**	0.025	0.450	0.980
INCOME	0.656	0.567	1.299	1.910
CATTLE	0.178**	0.089	40.99	1.210
CROP	0.012**	0.001	20.573	1.003
BIOAWA	0.002***	0.000	31.313	1.000
TECHAVAB	-0.370	0.490	0.563	0.433
FWSD	-0.003***	0.000	22.342	0.682
WATERASD	0.005***	0.003	20.475	1.005
SLC	0.557	0.352	1.398	1.875

***, ** and * significant at $p < 0.01$, $p < 0.05$, and $p < 0.1$ respectively.

-2 log likelihood = 170.365.

Hosmer and Lemeshow test $\chi^2 = 5.33$

Cox and Snell $R^2 = 0.523$

Nagelkerke $R^2 = 0.648$

% of accurate approximation for biogas users = 92.6 (67 households from 72).

% of accurate approximation for non-biogas users = 90.5 (116 households from 120).

% of overall accurate approximation = 91.6 (183 households from 200).

Most of the development programmes focus and aim at the technical characteristics in the promotion and dissemination of new technologies (Kabir and Yegbemey, 2013). The results from the study, however, indicated that the considered socio-economic characteristics and the biophysical conditions are essentially vital in promoting and disseminating biogas technology, as these factors could influence the choice of whether to adopt the technology or not at household level. In the advancement and management of biogas technology, the problems are more than technical. The all-inclusive factors and issues consist of human socio-economic, institutional, environmental and socio-cultural characteristics, and need to be considered essentially. This study found that the age of the household head has a positive correlation ($p < 0.01$) with the adoption of biogas technology. Hence, the chances of older household heads adopting the technology were higher than those of younger household heads. These results correlate with the findings of Nhembo, (2003), who found the old age is associated with conservatism, and in turn could influence their decision in adopting a new technology, as old age is sometimes likened to having higher economic standing, which will allows them to partake in a capital-intensive technologies, when compared to their younger counterparts.

The educational level of the head of household was one other key factor believed to influence the adoption of biogas technology. In the present study, a statistical significance ($p < 0.01$) indicates a positive relationship between education level and adoption of biogas technology. The relationship shows that there was an increased chance of about 2% of adoption by heads of households with more formal education. This indicates that educated people are more environmentally knowledgeable and conscious about the detrimental impact of fossil fuels on the environment. Hence, educated people are willing to try new technologies that can help abate the emission of greenhouse gases. These results correlate with the findings of Kabir and Yegbemey, (2013); Mengistu *et al.,* (2016) and Mwirigi *et al.,* (2009), whose studies found a positive association between the level of education and biogas technology adoption; thus, proving that lack of education is crucial and limits the spread of biogas technology. This is because to successfully promote the adoption of biogas technology it is paramount to educate the intended beneficiaries of the health, environmental and socio-economic benefits that the technology can provide, as this will accelerate the uptake of the technology.

At household level, gender established a significant ($p < 0.01$) positive association with the intention to adopt biogas technology. Households headed by females or males seem to have a significant probability of adopting biogas technology. The results from the odd ratio (1.6) on gender indicated that the head of household as a factor was statistically significant in adoption of the technology. This is because females dominate and cater most of the house chores, such as fuelwood collection, preparing meals, home maintenance and waste management. However, this has not stopped their male counterparts from embracing the technology. It is expected that adopting the technology will lessen the burden on their domestic work and chores. This result has controverted the hierarchical relationship that exists like in most other households in developing countries, where in family settings, mainly in rural areas, exhibit male dominance and female subordination in terms of household resources. Furthermore, in the households, men dominate ownership and decision making regarding the resourceful and investment means. The results however contrast those obtained by Kabir and Yegbemey, (2013) in their studies in Bangladesh, in which females headed households were more likely to adopt biogas technology than their male counterparts.

From the study, the average household size ranges from 4 to 7 members, which suggests a large household that is appropriately required to offer household labour for the running of a biogas digester. however, this was significant at $p < 0.05$, but had a negative relationship with the adoption of biogas technology at household level. A larger household was expected to motivate and ease the adoption of the technology, by providing the labour needed for the routine maintenance of the digester. The result does not statistically conform to the finding of Walekhwa *et al.,* (2009) in Uganda, on the critical factors that influence the adoption of a family-size digester. A dedicated household can feed their digester, as it only requires the mixture of water and dung as input at the same ratio. The income earned in the household was established with a significant positive statistical association ($p < 0.01$) in the study. This indicates that there is a positive correlation between income earned by household heads and the decision to adopt biogas technology in Limpopo Province. In Table 5.1, the odd ratio results of 1.91 indicate a positive influence of income to the adoption of the technology. The cost of installing a smallholding biogas digester is of R15 000 to R 80 000 (Tiepelt, 2015; Amigun and von Blottnitz, 2010; Mukumba *et al.,* 2016), which is considered too high for rural households. Most of the households in the rural areas often depend on government grants, pension and remittance from family members in urban centres. These results correlate with the household survey on energy related behaviour and perceptions in South Africa using the energy expenditure approach for income status, which indicated that 72%, representing nearly three-quarters of all households in the poorest quintile, are energy poor (Statistics South Africa, 2011).

The primary substrate considered for biogas digesters for gas production in Limpopo Province is cow dung. However, there are other sources of feedstock at household level, which can be used such as crop residues, pig, donkey and horse manure, chicken droppings, fruits and vegetables wastes and other household biodegradable wastes (Mukumba *et al.,* 2016). Consequently, the number of cattle owned by households increases the chances of adopting the technology. The approach by government corporations engaged in the biogas programme in South Africa targets households with a minimum of four or more cattle. Daily, a minimum of 20 kg of dung is supposed to be produced by these cattle, which is enough substrate needed for a small scale-sized digester of 4 m^3 to function. The production of 1.0 m^3 of biogas per day is sufficient to power a two-plate gas stove for a couple of hours (Tiepelt, 2015). From the survey results, the average number of cattle owned by households stands at four for users and non-users of biogas technology. This is satisfactory for the production of substrate for the operation of the technology at household level. However, the common free-range practice of cattle rearing could affect the quantity of the available dung for biogas production.

Significantly ($p < 0.01$), an increase in the herds of cattle owned by households, positively increases the chances of adopting the technology by a factor of 1.21. This result correlates with the outcomes of other studies that the number of cattle owned has a significant relationship with the intention of a household to adopt biogas technology. Crop production established a significant relationship ($p < 0.01$) with the intention to adopt biogas technology at household level in the province. Furthermore, the province, most of the digesters are in rural households that also engage in subsistence farming. While some households do not rear or own cattle, they buy the dung, in order to accomplish two objectives: production of gas for cooking purposes and utilising the slurry as good fertiliser option, to increase crop yield on the farms. Awareness of biogas technology was statistically significant ($p < 0.01$) in the adoption of the technology at household level in the province. Increased awareness of the technology concerning the gains of renewable energy also increased the probability of adopting the technology. Information and knowledge from family, friends and media are key in promoting the technology. Inayatullah and Waqar, (2018), reported similar findings in their studies in Pakistan. Technical support availability is another factor considered to influence the adoption of biogas technology at household level in the province. The statistical results revealed that technical availability was significant at $p < 0.05$, but with a negative coefficient of -0.37, implying that households opted for the adoption of biogas technology despite the little technical support available. This could be attributed to government approach in promoting the technology, where the digesters were constructed and installed by the government but maintenance services became a problem. The unavailability of technical support for the routine maintenance has led to many of these digesters being abandoned due to non-functionality. This discouraged other prospective users from considering the technology.

The distance from home to the fuelwood collection point was also believed to influence household decision on the adoption of biogas technology, as it is anticipated to reduce the burden of the heavy loads of wood carried. However, away from home, the distance of fuelwood collection sources increases the opportunity cost of the fuelwood collection (Guta, 2014). This result indicates a negative association (-0.003 coefficient; 0.68 odd ratio) between distance and source of fuelwood collection. Even though the households are experiencing a scarcity of fuelwood and there is a need to trek long distances, these have not influenced their interest in adopting biogas technology as an alternative. The respondents indicated that while biogas may be suitable for cooking, there are other unsuitable factors in the technology, compared to fuelwood. At household level, in respect to warmth, unreliability of the technology on cloudy days and faulty designs of the stoves, which cannot accommodate the three-prong-leg pots, which they normal use in preparing local meals, can be accommodated by fuelwood. Unrestricted and uncontrolled access to forests, where any resident can go and harvest fuelwood, is another factor that has limited the adoption rate. A few, however, still hold the view that food prepared with fuelwood tastes better than food prepared with other heat sources. The results contradicts the findings of Mengistu *et al.,* (2016) in Ethiopia, which found that distance to fuelwood collection and scarcity influenced the adoption of biogas technology.

The study results also showed that water source and availability are within the compound where the biogas digesters are located. Water is a vital component in the proper functioning of a biogas digester and was expected to be a factor to certainly affect the adoption of the technology at household level in the province. The statistical results thus indicate a positive relationship with an odd ratio of 1.005. This result correlates with that of Eshete *et al.,* (2006) on the feasibility study report in Ethiopia on the national programme for domestic biogas.

The statistical results show that access to credit, loans and subsidies are noteworthy factors in the adoption of the technology. The availability of these variables are expected to increase households' verdict on the adoption of the technology by a ratio of 1.87. Access to credit, loans and subsidies will enable the poor and empower households interested in the adopting the technology. This factor can also help in accelerating technology dissemination; thus, the provision of credit, loans and subsidies for biogas construction is relatively essential. The results of credit loan and subsidies as influencing factors in the adoption of biogas technology are in line with the findings of Mengistu *et al.,* (2016), which showed a similar statistical relationship with the adoption of the technology in Ethiopia.

5.4.4 Factors affecting biogas technology utilisation in Limpopo Province

Besides the factors that influence the adoption of biogas technology at household level in the province, the survey results also indicated several factors, which affect the potential of utilising the technology. These factors include sociocultural phenomena and climate. Socio-cultural phenomena strongly influence the implementation of new technology, especially when it relates to enhancement of societal lifestyles (Leung *et al.,* 2005). Two combined factors; namely, social and cultural aspects exhibit a strong relationship, as one aspect has a control influence on the other. Some beliefs have strict rules in reverence to cleanliness, which to a large extent not linked to humans alone, but also to animal faeces being used for cooking (GTZ, 1999). The social impact, denoted by friends, colleagues and family member, has a strong influence on the utilisation of biogas technology. The survey results also revealed that 72% of the households are reluctant to use it, despite adopting the technology. This is due to socio-cultural predisposition.

Temperature in biogas production is a critical factor, as it affects the activities of the methanogens. Furthermore, sudden temperature changes adversely affect gas production as the methanogen becomes inactive due to temperature variations. For anaerobic digestion, the optimal temperature for mesophilic bacteria is around 30-40 ^{0}C and between 50-60 ^{0}C in thermophilic bacteria. An ambient temperature of below 10 ^{0}C virtually stops the production of gas (Wang, 2014). Although, the provincial climate is sub-tropical, with an average rainfall of 300 to 1000 mm per year, there is great fluctuation in the weather conditions. This is due to the intersection of the Tropic of Capricorn as daily temperatures vary with an average range between 17 ^{0}C and 45 ^{0}C in the summer and 4 ^{0}C to 20 ^{0}C in the winter period, which are sometimes characterised by mist. Fluctuation, for example, in temperature needs a longer Hydraulic Retention Time (HRT), in order to accomplish stable gas production. The HRT is the number of days a substrate stays in the digester, and this depends on the temperature, the structure of the digester and type of feedstock used as input (Wang, 2014). Furthermore, households complained about the retention time for the substrate to ferment, which depends on the climatic conditions and range from 3 to 100 days.

The loading rate is also a basic factor affecting the utilisation of biogas technology at household level in the study area. The loading rate is the raw material amount fed per volume unit of the capacity of the digester per day depending on the volume of the digester and substrate concentration. The loading rates are units of mass of substrate per day (Wang, 2014). For 58% of the households, the loading rate, which is calculated by dividing the volume of the plant by the daily volume of substrate, is lacking, hence creating inappropriate mixture of substrate. For example, the ratio of water to substrate leads to under and over-feeding of the digester. Most households that have adopted the technology are frustrated by the continuous use of the technology to meet their domestic needs. This is due to unresolved problem(s) around their digesters, caused by the unavailable technical support and assistance, as reported by 74% of the households surveyed. The problems ranged from blocked pipes, valves, collapsed digesters and minor repairs that needed professional assistance. For example, most designs of the biogas stoves do not properly fit on the three-leg-pots used by most households in the province. The three-leg pot is used mainly for the preparation of most of the households' traditional and local meals. For 60% of the total households surveyed as adopters of the technology, the issue of stove design has hindered their ability to continuously use the technology. A cheap and easily accessible alternative source of cooking energy, such as fuelwood, plays a major part in the households energy mix in the province. This is due to the vast and almost unrestricted access to forest. Furthermore, most of the households are in the low-income bracket, thereby relying on almost any alternative source of energy, in order to augment their energy demands. Thus, it will be quite difficult to completely rule out the use and dependence on fuelwood by these households. Thus, about 98% of households with digesters still use fuelwood as an alternative fuel source to meet their day-to-day energy demands for domestic purposes.

5.5 Summary

The empirical evidence from the correlation of factors influencing household decisions on the adoption and utilisation of biogas technology are provided in this chapter. The variables were analysed and computed using a descriptive statistical technique of the logistic regression model. The users of the technology highlighted various reasons as the motivating factors in the adoption and utilisation of the technology. Households' decision were guided by allocation of resources including the assumption of a number of alternative available to them. In adopting the technology, households evaluated the technology based on its technical, sophistication, economic, environmental commercial social. Other aspects considered are the potential of the technology in providing employments as well as the ease of operating the technology.

From the twelve variables in the analysis, the odd ratio confirmed that nine of the variables were statistically significant, at ($p < 0.01$) in influencing the adoption of biogas technology in the households. The variables were age of heads of households, household head's level of education, number of cattle owned, distance to fuelwood source, gender, crop production, credits, loan and subsidies, income, awareness and water availability. These variables were found to have a positive relationship with the adoption of biogas technology. Three variables; namely, distance to fuelwood source, household size and technical availability, were also found to be statistically significant, at $p < 0.05$, although they were associated negatively with the adoption of biogas technology. This indicates that the probability of a household adopting the technology increases with the effects of these variables and vice versa. This chapter gives credence to the next chapter, which is on the role of biogas technology in emission reduction from fuelwood consumption in Limpopo Province.

CHAPTER 6

THE ROLE OF BIOGAS TECHNOLOGY IN EMISSION REDUCTION FROM FUELWOOD CONSUMPTION IN LIMPOPO PROVINCE

6.1 Introduction

Worldwide, between 2012 and 2040, energy consumption is expected to increase by 48% with the annual highest average change (2.6%) to occur in Africa. Worldwide, biomass contribution (that is fuelwood) to the total demand for energy is about 15% and in some developing countries, it stands at 86% (FAO, 2016). For nearly 90% of its domestic supply of energy, tropical Africa largely depends on fuelwood. This is because it is still a cheaper form of energy than most available alternatives forms. For example, with the constant price increases of the 1970s, fuelwood did not show any price increment in its trend and even if the price was to increase, the demand would not be drastically reduced, due to unavailability of substitutes (Boahene, 2008). Moreover, the magnitude of fuelwood use as a source of energy and its consumption rate are influenced by a number of factors, including cultural phenomenon, demand, household sizes and environmental conditions (Kituyi *et al.,* 2001).

In most developing countries, there are many faces of poverty, one of which is coping with the limited means and lack of efficient energy technologies in households. In most Sub-Sahara African communities, poverty could mean among other things, having to primarily rely on dung and or wood for cooking and heating purposes. For these rural communities, for them to meet their household energy needs and demands through fuelwood, large portions of land are cleared, along with its vegetation, thus creating degradation and deforestation. This results in devastating environmental consequences. Estimates have revealed that every year, Africa is experiencing a net of nearly five million hectares of tropical forested land (Awino, 1999). Therefore, Sub-Sahara Africa thrives on a very fragile environment that is threatened by deforestation, soil erosion and biodiversity loss, among other environmental concerns. According to Masekoameng *et al.,* (2005), as in many developing countries, in South Africa, many rural areas are less privileged in terms of infrastructure and social amenities compared to urban areas. Where there are available services in these rural areas, they are customarily of low quality and limited in standards. With a fairly large population living in these areas, even the energy consumed in these rural areas is mainly from traditional sources, such as cow dung and fuelwood.

A study conducted by Broadhead *et al.,* (2001) for Food and Agricultural organisation (FAO) have revealed that developing countries, Africa in particular, are highly dependent on fuelwood as a major source of energy. On the other hand, other regions of the world have shown a steady decline in fuelwood consumption. The demand in Africa is projected to tremendously increase until about 2030. Figure 6.1 shows the global projection trend in fuelwood consumption.

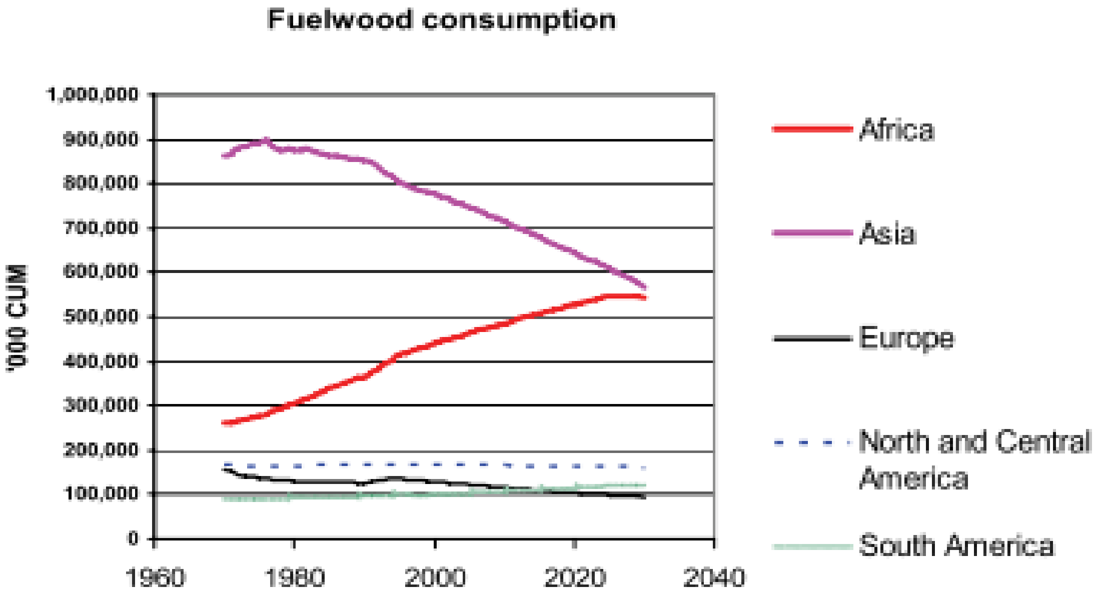


Figure 6.1: Past trend and future prospect of global utilisation of fuelwood for energy 1960-2040 (Broadhead *et al.,* 2001).

According to the best available figures, the use of energy in households in developing countries totalled 1 090 Mtoe in 2010, representing almost 10% of world primary energy demand. Biomass use in households of developing countries alone accounts for almost 7% of world primary energy demand (IEA, 2017). Essentially, variations exist in the levels, types and consumption of fuels used as energy and the actual breakdown is difficult to obtain, but in developing countries households, energy is used mainly for cooking, followed by heating. In many countries, due to climate and geography, household space and water heating needs are usually very small. Generally, households use a combination of energy sources for cooking, which can be categorised as traditional (fuelwood, dung and agricultural residue), intermediate (Paraffin/kerosene and charcoal) and modern (Liquefied Petroleum Gas and electricity). Electricity is used often for lighting and small appliances, rather than for cooking (IEA, 2017).

However, in many developing countries there are abundant biomass supplies but local scarcity still exists and in some households thus, biomass is the only affordable source of energy. The commercial production and distribution of fuelwood and charcoal significantly generates employment and income for some rural households in developing countries. However, a switch to alternative fuels will also create business opportunities and employments (FAO, 2004).

In some Organisation for Economic Co-operation and Development (OECD) countries and in most countries in economic transition, there are technologies available to convert biomass to energy, which tend to be very efficient. The resources are generally harvested in a sustainable way. However, in developing countries, the technologies and practices are poor and far less efficient and poor. Many households use three-stone fires, cook without ventilation or harvest trees in an unsustainable manner. Dependence on biomass resources is important for many communities, but it cannot be viewed as sustainable when the use impairs health and create negative environmental and economic impacts (OECD, 2006). A compilation using survey, census data and direct correspondence with national administration in developing region for each country indicated that the number of people that rely on biomass as their main fuel for cooking is at over 2.5 billion people or 52% of the population. Developing countries depend on biomass for cooking. Over half of these people live in Indonesia, India and China. Yet, the proportion of the population that relies on biomass is the highest in Sub-Sahara Africa (WHO, 2006).

In several Sub-Sahara Africa rural communities, more than 90% rely on fuelwood and charcoal as the main energy source for cooking. In Latin America and Asia, poor households are also dependent on fuelwood as their energy source for cooking (FAO, 2004). Dependence on biomass is concentrated in, but not restricted to rural areas alone. Nearly half a billion people in urban centres also rely on these resources. In addition, urbanisation is associated with lower fuelwood consumption. Furthermore, the use of LPG on towns and cities is not always evenly spread (Jannuzzi and Sanga, 2004). In urban centres of Sub-Sahara Africa, more than half of the households rely on fuelwood, wood waste or charcoal, to supplement their cooking needs, as over a third of the households in urban Asia also rely on these fuels (FAO, 2004).

In households, the share of biomass widely varies across regions and countries; hence, reflecting primarily not only their endowments of resources but also their economic level of development urbanisation. For example, in Thailand where average per-capita income stands at $2 490, biomass account for 33%, whereas the share is nearly 95% in Tanzania (World Bank, 2006). In addition, there are important differences between urban and rural households. For instance, fuelwood for cooking purpose is three times more important in rural areas than in urban areas in both Botswana and India (Census of Botswana 2001 and Census of India 2001). In the 19th century, the majority of the world energy supply was from biomass and fuelwood, which represents one of the oldest form of energy supply. A decade ago, the Food and Agricultural Organisation (FAO, 2007) estimated that annually, 3.3 billion m^3 of fuelwood was harvested globally and that approximately, 73% of Africa's population relies on fuelwood as their source of primary energy (Bailis *et al.,* 2007). According to the International Energy Agency (IEA, 2004), the number of people that rely on fuelwood as their source of energy would increase from about 575 million in 2004 to about 918 million people in 2030. Twenty years ago, Williams and Eberhard 1996, estimated that in South Africa, 13 million m^3 of fuelwood was consumed annually. In the same period, the population of South Africa has grown from 42 million to 56 million (Statistics South Africa, 2011), along with the demand for energy.

Simply put, households do not substitute one fuel for another, even if the income increases. Instead, they add another fuel in the process known as "fuel stacking". Modern energy forms are usually applied economically at first and for particular services (for example, electricity for refrigeration, television and radio or LPG for making coffee or tea), rather than taking the place of an existing energy form that adequately supplies a service. Ordinarily, the common consuming activities in the house are cooking and heating and usually the last to switch. Generally, using multiple sources of fuel in the household provides a sense of energy security, as total dependence on a single fuel or technology leaves the households vulnerable to unreliable service and price fluctuation (Jannuzzi and Sanga, 2004). Some reluctance to discontinue cooking with fuelwood may also be attributed to taste preferences and familiarity of cooking with traditional technologies. In India and many other countries, many wealthy household still retain a woodstove for baking traditional bread (Rwelamire, 1999). However, as income increase, fuel options begin to widen up, and the fuel mix may change but fuelwood is rarely excluded as an energy source. In South Africa, Limpopo Province has exhibited a higher rate of fuelwood consumption than any other provinces in the country. Furthermore, the province forested land is in steady decline due to over-exploitation of the forest resources. Most of the households, particularly those in the former homelands, still do not have access to an adequate supply of electricity from the national grid, thus resort to traditional energy sources to meet their demand, with fuelwood as one paramount source.

6.2 Energy, Atmospheric Emissions and the Environment

The bulk of global energy supplies come from carbon-based fuels, whose emissions threaten the environment, human health, climate and the earths very existence (UN-Energy/Africa, 2011; UNEP, 2012). Energy-related emissions are the core drivers of anthropogenic climate modification, aggravating patterns of environmental degradation and global warming, with three major greenhouse gases; namely, carbon dioxide, methane and nitrous oxide being responsible. Global emission of carbon dioxide (CO_2) has increased more than 46% since the late 1990s (UNDP, 2013). Precisely, emissions from fossil fuel burning have been reported to have reached a record high of 31.6 gigatonnes (Gt) in 2011, and in 2035 global greenhouse gases emission are projected to increase to an annual 37 giggatonnes (IEA, 2014).

Commonly, it is presumed in nature that biomass fuels are renewable and greenhouse gases neutral, because during combustion the carbon released in the form of carbon dioxide is taken up by the re-growing vegetation. Thus, the burning of fuelwood could result in the net emission of carbon dioxide, by decreasing the forest area and standing stock of carbon in forests (Subedi *et al.,* 2014). Fuelwood contributes to greenhouse gas emission through unstainable harvest and in the process of incomplete combustion. The burning of fuelwood gives rise to emissions of GHGs because dry wood contains about 50% carbon. However, the carbon content in a growing tree is much lower because they contain a higher proportion of than dry wood. When one metric ton of dry wood are burnt 1.833 metric tons (1833 kg) of carbon dioxide is emitted (Lamlom and Savidge, 2003).

The emission of GHGs has been identified through the Intergovernmental Panel on Climate Change (IPCC) as a key cause of climate change and the changes are regarded as any climatic change over time owning to natural variability and or human activity. From human-induced (anthropogenic) greenhouse gases, carbon dioxide, methane and nitrous oxide account for 92% of the total emission (World Bank, 2006). Generally, in Africa, carbon dioxide emission have increased twelve-fold, reaching 311 million metric tons in 2008, which is still less than that of some single countries like China, Japan, Russia, India and the United States of America. In Africa, from all sources of fuels over time, emission has grown in all regions of the continent at approximately 35% (Boden *et al.,* 2011).

In Africa, however, a small number of countries are mainly responsible for the emission of fossil fuel. South Africa alone accounts for 38% of the total emissions, with the combination of Nigeria, Libya, Egypt, Morocco and Algeria accounting for 46% from the continent. On the continent, these six countries have annual carbon dioxide emissions in excess of 10 million metric tons. Four countries from the continent have a per capita carbon dioxide emissions higher than the global average of 1.3 metric tons per year. They are Libya with 2.53, South Africa 2.9, Seychelles 2.22, and Equatorial Guinea with 1.99 (Boden *et al.,* 2011).

Without policy action, the rate of emissions is expected to increase and this will veer weather patterns and temperature that civilisation has adapted and even further away from the norm. The promotion of renewable energy can assertively reduce carbon emissions from energy use, due to its potential to save equivalent of 220 to 560 gigatonnes of carbon dioxide between 2010 and 2050 (IPCC, 2011). Greenhouse gases can be measured by recording the emission at source or by estimating the amount of emitted gases – multiplication of activity data (amount of fuel used) with the relevant emission factors. In cooking systems for example, the emission factors forms the basis of estimating the emission and the conversion factors allows activity data (tons of fuel or litres used) to be converted into kilograms of carbon dioxide equivalent (CO_2). The carbon dioxide equivalent is a universal unit of measurement that allows the global warming potential of different greenhouse gases to be compared (IPCC, 2011).

Increases in the concentration of carbon dioxide and other greenhouses gases in the stratosphere will lead to global warming and eventually climate change. This change will further lead to adverse effects on ecological productivity, water reserves, biodiversity and human health of the socio-economic groups that have low adaptive capacity, which are often the poor in developing countries. Climate change can exacerbate poverty and undermine sustainable development (IPCC, 2011).

According to Stern (2006), in order to reduce the harmful consequences of climate change, there is a need to stabilise the concentration of greenhouse gases below 550 ppm of CO_2eq. The review argues further that any delay in the reduction of the emissions will be dangerous and costly (IPCC, 2011). The endeavour to control the emissions of GHGs to the atmosphere is crucial, as global mitigating efforts can enhance the prospect of sustainable development by reducing the threat of the adverse impacts of climate change. Co-benefits can also be provided through the mitigation processes, such as better livelihoods and improved health standards. Thus, mainstreaming climate change mitigation is an integral part of sustainable development.

In attempting to mitigate climate change, the energy sector has a pivotal role to play. This is biogas technology has an important climatic effect and therefore, a mitigating mechanism against global warming and climate change. In converting methane into fuel, the use of biogas reduces carbon dioxide emissions, through reduced demand for fossil fuel and fuelwood. A study conducted in Nepal indicated that a biogas plant of 6 m^3 can potentially save about 32 litres of paraffin (kerosene) and more than four tons of fuelwood (Mendis and van Nes,1999). Using manure for biogas production has triple benefits: it represents a valuable starting point in mitigating methane from the atmosphere; secondly, it is locally affordable and available raw material for bioenergy production and the slurry can be used as fertiliser compost. Renewable energy also has some potential in creating employment, enhancing energy security, mitigating climate change while also enabling developing to make substantial foreign exchange and savings (UNEP, 2012).

6.3 Biogas technology as an alternative energy source

Biogas technology offers a viable, cheap and renewable solution to the energy problems confronting most households in Limpopo Province, particularly in the rural communities, with the merit of using feedstock from traditional waste that has been considered useless. The technology involved in biogas technology to produce gas is relatively simple and can be efficiently and cheaply implemented through small scale-digesters that can be used and maintained easily. Small-scale digesters can offer multiple benefits to the entire circles of the communities but have a direct bearing to the need of the households (Tiepelt, 2015).

The much anticipated revival of sustainable energy envisaged in developing countries can be augmented by renewable energy sources, such as biogas (Amigun and von Blottnitz, 2007). It is a less expensive option and ideal for low-income groups, and with the necessary required inputs, it is affordable, accessible and can be managed locally. In the existence of large quantities of municipal, industrial and agricultural wastes, the production of biogas can be effectively used for electricity generation and the residues as agricultural fertilisers (Smith, 2011). Digesters are relatively economical, with simple operation from large to small scale in rural places. In that respect, biogas technology is assumed to play a vital role in complementary other energy sources (Amigun and von Blottnitz, 2007). The use of the technology offers multiple benefits to the users. These include in the course of anaerobic digestion, organic nitrogen is converted to ammonium in the compost, which is a key component in fertilisers (Ghafoori and Flynn, 2007). Additionally, the offensive smell can be eased out from inappropriately managed or encumbered manure in the process of anaerobic digestion, which could compromise the air quality and pose a nuisance to the surrounding communities. Furthermore, the bacteria consume the unpleasant odours with volatile organic content and compounds that produce odours in the system during gas production (Hill and Bolte, 2000). Biogas is flexible energy that is required in several applications, as it can also be used for cooking and lighting. Even if it is a low-pressure gas cooker, it is practically easy and effective to conventionally use the gas straight in a burner (Hill and Bolte, 2000). Nowadays, in several countries, the gas from the technology is either used for combine heat and power generation (CHP) or advanced and fed into the gas grids in fuel cells, or used as vehicle fuel (Ghafoori and Flynn, 2007). Over the past decades, the method of gas production from biogas technology as form of renewable energy has become a global concern. It is a gas rich in methane, formed by anaerobic digestion by dissolving organic materials, which is different from other sources of renewable energy such as thermal, solar hydro and wind (Pereira, 2009).

The role of biogas technology is widely acknowledged in reducing greenhouse gas emissions and improving energy security supply in households, particularly where challenges of energy supply exist. The technology has overwhelming environmental characteristics, which has resulted in a net negative dispensation of carbon dioxide and low sulphuric content (Erdogdu, 2008). Proper and functional biogas technology can offer several advantages to the society and the users resulting in environmental conservation and protection of resources, with a noteworthy impact on sustainability of energy supply and security (Yadvika *et al.,* 2004). Fundamental development of sustainable energy is impeded by fossil fuel reliance because it is expensive, exhaustible and unreliable. Biogas technology can contribute to the diversification of strategy energy sources and also be a significant energy replacement, making it a vital energy source for national economic security (Erdogdu, 2008). In India, an evaluation by Pal (2002), indicated that a biogas digester that can produce 2 m^3 of gas per day which can effectively replace roughly 27 – 300 kg of fuelwood per month. Studies on the technology carried out in Zimbabwe also indicated that using biogas for cooking was more efficient than conventional fuel (Matsvange *et al.,* 2016). Furthermore, using the technology provides health benefits compared to burning of fuelwood (Walekhwa, *et al.,* 2009). Concerning energy, with time, it is apparent that renewable sources of energy will ignite a more central role than conventional energy sources (Iniyan and Jagadeesan, 1997).

Biogas energy will in future play a crucial role in the production of green power in the world because it offers the opportunities to influence more organised system of electricity generation where a plant is designed to meet the consumer needs, maximizing availability and preventing transmission failures (Akpinar *et al.,* 2008). In addition, it proffers a favourable circumstance in increasing, diversifying and completion in power generation within the economy (Erdogdu, 2008). Possibly, the most important of the many advantages of the technology is that it can offer a decentralised solution to the energy crisis often associated with South Africa rural communities. In addition, biogas technology stands out as a good alternative source of energy in Limpopo Province due to the availability of feedstock mainly cow dung. The bushveld grassland of the province is renowned for cattle rearing and other livestock farming. Biogas technology can help ameliorate the issue of greenhouse gas emissions, provide succour in providing energy to the households especially those in the former homeland. The adoption and utilisation of the technology can also reduce the pressure on the already declining forested land.

6.4 Research methodology

Data for the study were elicited using a spring balance to measure the mass of fuelwood used before and after the installation of biogas technology in the households. The measurements were recorded in the questionnaire, together with other socio-economic and demographic information obtained from the households. The data were analysed using the IPCC generic formula for the estimation of greenhouse gas emissions.

6.5 Results and discussion

6.5.2 Fuelwood consumption measurement

The daily per capita fuelwood consumption per household for the 72 sampled households with biogas digester was 946 kg, while for 128 households without biogas digesters it was 2436 kg. Furthermore, in determining the per capita consumption of fuelwood, the sum total is divided by the sampled households with and without biogas digester, which is 72 and 128 respectively.

6.5.2.1 Emissions of greenhouse gases (GHGs)

The total carbon calculated values of CO_2, CH_4 and N_2O emissions from the surveyed households installed with and without biogas digesters are presented in Table 6.1.

Table 6.1: Fuelwood consumption and GHGs concentration emissions from household with and without biogas digester.

	Household with biogas digester	Household without biogas digester
Average fuelwood consumption per day	13 kg	19 kg
Average fuelwood consumption per month	390 kg	570 kg
Average fuelwood consumption per year	4680 kg	6840 kg
Average CO_2 emitted daily	21.47 t	31.37 t
Average CO_2 emitted monthly	644 t	941 t
Average CO_2 emitted yearly	7728 t	11293 t
Average CH_4 emitted daily	0.10 t	0.13 t
Average CH_4 emitted monthly	3 t	3.9 t
Average CH_4 emitted yearly	36 t	46.8 t
Average N_2O emitted daily	0.00065 t	0.00094 t
Average N_2O emitted monthly	0.020 t	0.028 t
Average N_2O emitted yearly	0.24 t	0.33 t

From table 6.1, it can be noted that the respective daily outcomes were found to be 21.47, 0.10 and 0.00065 t. This gives a projected contribution of the total emissions from the Limpopo Province to the country's budget. This was further tested with a chi square test at 0.05 level of significance. The results $p < 0.05$ indicated that there is no statistical significance in fuelwood consumption between households with and without biogas digesters. The intergovernmental Panel on Climate Change (IPCC, 2016), identified greenhouse gas emissions from human actions as one of the primary causes of global climate change, which is considered as any change in the climate over time due to human activities, indirectly or directly as well as from natural variabilities. Among the human-induced (anthropogenic) greenhouse gas emissions, methane, carbon dioxide (CO_2), and nitrous oxides account for 18%, 67% and 7% respectively (World Bank, 1998).

The concept of Global Warming Potential (GWP) has been developed to compare the climate changes impact of different greenhouse gases. Based on this comparison, it gives a warming expression of all greenhouse gases prediction that could occur because of increased GHGs emissions. Global warming is defined as the progressive and gradual rise in temperature of the earth surface, which is believed to be caused by the effect of greenhouse gases, resulting in changes in global climate patterns. To assess the Global Warming Potential, the strength of other greenhouse gases is compared to carbon dioxide, with an assigned value of '1' on the GWP index for a '100 years' time horizon. The Global Warming Potential indices for methane and nitrous oxide are 21 and 310 respectively. This means that on a ton-for-ton basis in trapping heat, methane and nitrous oxides are anticipated to be 21 and 310 times more potent than carbon dioxide.

6.5.2.2 Estimation of biogas potential in the study area

From the data collected from households with and without biogas digester, the average number of cattle owned per household is four (4), field survey.

A zero grazed cow produces an average of 10 kg of dung a day. However, in the study area, cattle are kept using the free ranging system that are kraalled at night. Thus, it is assumed that only 50% of the cow dung will be available for biogas production.

Available dung as substrate for the digester = 5 kg (heard of cattle) $^{-1}$ (6.1)

Total substrate available per household = 5 x 4 = 20 kg day $^{-1}$ (6.2)

Cow dung is mixed water in equal ratio of 1:1 to for the slurry of specific density 1.089 (NABARD, 2007).

The substrate input for the digester is calculated according to equation 4;

Substrate input $S_{d} =$ Biomass available per household (B) + Water (W) (6.3)

$S_{d} = 20 + 20 = 40$ kg

Volume of substrate, $V_s = 40/1089 = 0.0367$ m^3

Therefore, the volume of the digester is determined as

$V_d = V_s \times RT$ (6.4)

Where V_d is the digester volume m^3; *Vs* is the substrate volume, *RT* is the retention time in days.

Biogas digester using cow dung requires a retention time of 50 days (CBRI, 1989).

$V_d = 0.0367 \times 50 = 1.83$ m^3

Daily gas production

The daily biogas production is calculated as follows:

$G = V_s \times G_y$ (6.5)

Where G is daily gas produced in m^3, V_s; substrate volume and G_y is the gas yield potential

The average value of 0.032 m^3 is considered to be produced from 1 kg dung (Bond and Templeton, 2011).

Therefore, the total substrate available multiplied the by gas yield potential of the substrate.

Volume of gas = 20 x 0.032 = 0.64 m^3.

6.5.2 Carbon emissions saving estimation

The amount of avoided carbon emission is dependent on the amount of fuelwood replaced by biogas technology, the net calorific value of the fuelwood and the fuelwood carbon emission factor.

6.5.2.1 Determining energy produced by a biogas digester

The energy produced by a biogas digester depends on the gas produced and the calorific value of biogas. The average calorific value of biogas is considered at 20 MJ/m^3 (Pathak *et* *al.,* 2009), thus the energy produced by a biogas plant is determined as the gas produced, multiplied the by the calorific value 0.64 x 20 = 12.8 MJ or 3.55 kWh of energy per day $^{-1}$

6.5.2.2 Thermal efficiency

Thermal efficiency for a conventional biogas stove is assumed at 55% (Perera and Sugathapala 2002); therefore, the useful energy equivalent is found to be 0.55 x 3.55 = 1.95 kWh day $^{-1}$

The thermal efficiency for a three-stone-stove mostly used is the study area is 13% (Perera and Sugathapala 2002), thus it will require more fuelwood to produce the same amount of energy generated from biogas. The total fuelwood replaced by biogas per day is obtained using the equation.

$$\eta = \frac{E_{out}}{E_{in}} \qquad (6.6)$$

Where

E_{out} is Energy output

E_{in} is Energy input

$$E_{in} = \frac{E_{out}}{\eta} \qquad (6.7)$$

η = 1.95/0.13 = 15 kWh

1 kWh is equivalent to 0.35 kg of fuelwood

15 x 0.35 equals 5.25 kg

With an equivalence of 0.35 kg of fuelwood for 1kWh energy, about 5.2kg of fuelwood is needed per day. Therefore, for every 1.95 kWh of energy produced from biogas, 5.25 kg of fuelwood is saved. The use of biogas as an alternative source of energy has not been completely relied upon due to the energy mix consideration of the households and the inappropriateness of the technology with cooking utensils as shown in Figure 6.2 and 6.3. In order to meet their energy demand, households fitted with the technology still rely on other sources of energy, and fuelwood in particular. The use of fuelwood could be largely attributed to the unrestricted access to the forest, which has left the households unhindered access to the forests.

Figure 6.2: A household with a functional biogas digester, herds of cattle and stockpile of fuelwood (Field survey, 2018). Permission to use by respondent.

Figure 6.3: A household with an installed and functional biogas digester using open fire (Field survey, 2018). Permission to use by respondent.

6.6 Summary

This chapter evaluated the quantity of greenhouse gases emitted by the sampled households as a direct result of fuelwood consumption. The daily per capita fuelwood consumption per household for the 72 sampled households with a biogas digester was 946 kg, while for the 128 households without biogas digesters it was found to be 2436 kg. Furthermore, in determining the per capita consumption of fuelwood, the sum total is divided by the sampled households with and without biogas digester, which is 72 and 128 respectively. The dial values for CO_2, CH_4 and N_2O were found to be 21.47, 0.10 and 0.00065 t. This gives a projected contribution of greenhouse gases from the sampled villages in Limpopo Province to the national emission budget. Further, the potential of biogas digester was estimated using the daily gas produced, carbon emissions that can be saved by the adopting and utilising the technology, the energy produced by the digester as well as the thermal efficiency of the technology.

CHAPTER 7

THE DEVELOPMENT OF A COMPREHENSIVE CONCEPTUAL FRAMEWORK FOR ADOPTION AND UTILISATION OF BIOGAS TECHNOLOGY IN LIMPOPO PROVINCE

7.1 Introduction

The initiatives of biogas technology are still in their infancy stages in many developing countries and face many challenges to their adoption and utilisation. In many countries, particularly the developing nations, the adoption and utilisation of biogas technology are less satisfactory. In some of these countries, government has invested large sums of money for biogas initiatives and one such country is South Africa, yet they still faces many shortcomings and issues that have slowed biogas adoption and thus minimise the utilisation of the technology (Ashira and Rasheed, 2017). In Limpopo Province, there are several factors and favourable conditions that support the promotion, adoption and utilisation of biogas technology. Most of the population in the province resides in the former homeland and are faced with the challenges of electricity supply. Furthermore, evidently from literature, the province is confronted with forest degradation and deforestation, which has an established direct and indirect link to fuelwood harvesting, and consumption leading to the depletion of the forest resources. The issue of global warming that has been of concern to most governments around the world. It is also a factor the province has to look at in order to adopt this eco-friendly technology, that can help abate the emissions of greenhouse gases into the atmosphere. From the empirical results, the province is endowed with sufficient feedstock from livestock farming that can efficiently sustain the operation of biogas technology.

The government, in its programmes, has adopted the top-down approach in the provision of biogas digesters for households in rural areas of the country, by promoting pro-poor energy alternatives through the projects "Design, development and monitoring of optimised sustainable clean renewable energy and efficient mix system. The government is also promoting organic waste-to-energy and other low carbon technologies in small, medium and microscale enterprises (SMMEs): Accelerating biogas market development: Capacity Building for Domestic Biogas Digesters". However, these projects have not produced the anticipated outcomes, despite the large monetary commitment from the government.

In literature, most of the studies focus on the potential of biogas technology from structural aspects (Betul, 2017; Ivan *et al.,* 2018 and Winkler *et al,* 2017). Many studies also focus on analysing the barriers to and implementing challenges of the technology (Mwirigi *et al.,* 2014).

However, from the households' perspectives, few studies have been carried out to ascertain and analyse the factors that influence the adoption and utilisation of biogas technology (Walekhwa *et al.,* 2009 and Mengistu *et al.,* 2016). Several theories and models have been developed in the study of diffusion and acceptance of technologies. Among these are the Unified Theory of Acceptance and Use of Technology (UTAUT), Technology Acceptance Model (TAM), Theory of Reasoned Action (TRA) and the Diffusion of Innovation Theory (DOI) (Taherdoost, 2018).

Some common theories and models are utilised in most research in analysing the adoption of technology either by using their original forms, or by the addition of certain constructs to the original or by the combination of both. Nonetheless, in evaluating their applicability in the levels of studying biogas adoption and utilisation, some of the theories and models that have been used in adoption analysis in literature were analysed critically in the present research. This helps in overcoming the shortcomings and filling the gaps, which exist in the studies conducted while developing the conceptual framework.

Significantly, some constructs involved in the analysed framework are imperative and are supported in the literature hence; they will be incorporated into the present framework. Conversely, certain constructs that are not supported in literature means they are not noteworthy. Therefore, they will not be considered for analysing the adoption and utilisation of biogas technology. Similarly, a number of factors that are significant and are likely to influence the adoption and utilisation of biogas technology were not addressed in some of the models analysed. Table 7.1 shows the reasons why some of the commonly used models and theories are not applicable in the analysis of biogas technology adoption and utilisation at household level. As previously stated, some current studies in literature have analysed technology adoption. The most common models used are highlighted in Table 7.1 (Taherdoost, 2018). The outcomes, therefore, were limited due to the existing limitations in the utilised frameworks. By adding extra construct, such as trust and risk, or through a combination of some common theories and models, their original form has been amended in several studies (Sang and Lee, 2009).

Table 7.1: Inappropriateness of some common models and theories for the adoption and utilisation of biogas technology in Limpopo Province.

The model	Inappropriateness in biogas technology context
TAM	• Excluded from TAM is some resource variance of importance and not considered in the model. For instance, the factor of income that can prevent a user from using or adopting the technology is not considered (Muk and Chung, 2015). • Not fully mediated in the *Perceived Usefulness* and the *Perceived Ease of Use* is the *Attitude towards using* the technology. • Not fully explored in the Technology Adoption Model (TAM) are the proposed *external variables* as an influencing factor that will affect the *Perceived Usefulness* and the *Perceived Ease of Use* (Lin *et al.,* 2011). • The TAM cannot specify and capture the whole essence of biogas technology behaviour usage because it lacks many factors that are important and constructs that directly impacts on behaviour in relations to intention to use and actual usage of the technology, particularly biogas technology (Maillet *et al.,* 2015).
UTAUT	• Some influential constructs on the other model are ignored in the UTAUT, which are very important in the analyses of technology adoption and utilisation such as biogas technology. • Not addressed in the UTAUT construct are some factors, which are very important such as performance and perceived awareness, which are likely and highly, to strongly impact on the intentions and behaviours to adopt and use technologies. Also not addressed in the constructs relates to the reliability aspect such as perceived regulations, trust and security. Furthermore, cultural influences are not addressed in the model in the adoption and utilisation of technologies such as biogas. Furthermore, influences of certain demographic factors such as gender and age, other personal demographic factors which are important were not address such as household's income, household's location and household's educational level which are very likely to influence the adoption and utilisation level of the user. • Labelling and grouping items in the UTAUT is quite problematic, as varieties of unrelated items are combined in representing a single construct (Venkatesh 2003).
DOI	• In the construct, *Observability,* which denotes the degree to which innovation affords tangible and visible results, implicitly, can be integrated into the construct of *Relative Advantage.* • Lacked in the DOI model are some constructs and factors that are fundamental when analysing the adoption and diffusion of new technology such as biogas. • In the DOI construct, *Triability*, which discusses experimentally how easily to use a new technology, cannot be applied to some technologies including biogas technology due to the user's perceptions; hence, such technology is not triable. This, however, does not mean that the testing and validating of the technology is not necessary or important.
TRA	• One of the least understood aspect of the TRA construct is the *Subjective Norm*. Through the *Attitude towards a behaviour (A) construct,* the *Behavioural Intention (BI)* is likely to be indirectly impacted on by the *Subjective Norm (SN)* (Taherdoost, 2018). However, this will directly influence the differentiation between *SN* on *BI* and indirectly influence *SN* on *BI* through *A.* • The TRA lacks some significant construct that can evaluate the adoption and utilisation of complex and large systems such as biogas technology.

7.2 Biogas Adoption and Utilisation Framework (BAUF)

A conceptual framework simply identifies the highest-level relationships that exist between entities. Included in the conceptual framework features are entities and the relationships among them. The primary objective of the framework is to convey the basic functionality and fundamental principles, which the system represents. In addition, it was developed in such a way that it provides easy understanding and interpretation of the system for the user of the framework. The rationale of the framework, when properly implemented, is to enhance understanding of the representative system, and efficiency conveyance of the system details between the stakeholders. Using the conceptual framework, incorrect requirements and the likelihood of unclear, incomplete and inconsistency are minimized.

In analysing the factors that influence the adoption and utilisation of biogas technology, this research developed an inclusive conceptual framework called Biogas Adoption and Utilisation Framework (BAUF). A comprehensive framework is provided for analysing the key factors that critically influences the adoption, utilisation and spread of biogas technology. Based on the development of the BAUF, crucial analysis of literature on technology acceptance, in combination with perceptions from other theories and models that are commonly used to analyse the technology acceptance and usage, were scrutinised. Shortcomings and defect existing in the theories and models used in biogas adoption in literature are addressed in the BAUF. The goal of this framework (BAUF), is aimed at determining the factors that influence the users' intentions, beliefs, as well as behaviour that could influence their adoption and levels of usage of the technology. This framework was informed and developed based on the parameters of empirical evidence from the results generated from the field survey. The linkage of the framework are sourced in chapter four, which deals with the evaluation of biogas technology awareness and perceptions; chapter five examines the factors influencing household decisions on adoption and utilisation of the technology, while chapter six examines the role of biogas technology in fuelwood emissions reduction in the Limpopo Province.

In the developed framework, three dependent variables; namely, *Readiness of Biogas Technology (RBT)*, *Intention to Use Biogas Technology (IUBT)* and *Actual Adoption and Utilisation of Biogas Technology (AUBT)* are presented in the BAUF. Four independent variables are also contained in the BAUF, which are *Personal Influences (PI), Economic and Motivational Influences (EMI), Technical Influences (TI), Environmental Influences (EI).* The fundamental factors are represented by these independent variables and can critically influence the levels of adoption and utilisation of biogas technology in the province. Figure 7.2 shows the conceptual framework of BAUF.

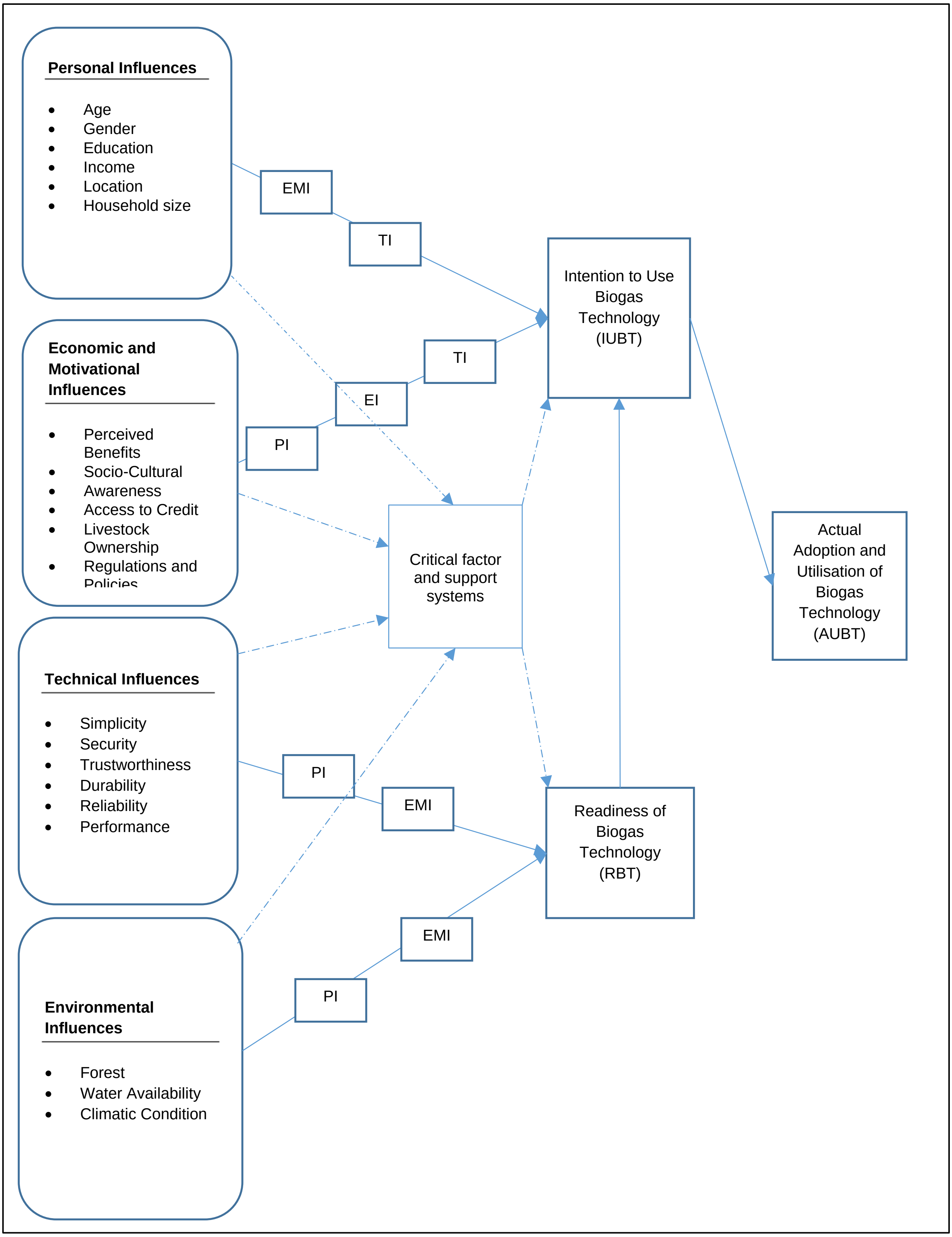


Figure 7.2: The Conceptual Biogas Adoption and Utilisation Framework (BAUF).

In the BAUF research constructs, the relationships between the variables have been represented in three ways. They are by arrows, indicating direct relationship, rectangles which represents the indirect relationships and dashed arrows, representing the direct and indirect relationship. In the construct, direct relationship for example means *Personal Influence (PI)* and *Economic and Motivational Influences (EMI)* have a direct influence on the *Intention to Use Biogas Technology (BI). Environmental Influences (EI)* and *Technical Influences (TI)* can also directly influence the *Readiness of Biogas Technology (RBT)*. In indirect relationship, it means one or more variables in a specific construct has/have an indirect impact; in other words, one or more variables in the construct can affect or influence other constructs indirectly. For example, one or more *Economic and Motivational Influences (EMI)* can indirectly affect the relationships between the *Personal Influence (PI)* and the *Intention to Use Biogas Technology (BI).* Furthermore, one or more of the *Personal Influence (PI)* can influence the relationship between *Technical Influences (TI)*, and *Readiness of Biogas Technology (RBT)* indirectly. The direct and indirect relationships are represented by dashed arrows as well as the critical factor and support systems that can help sustain the all the relationships regarding the adoption and utilisation of biogas technology in the province.

7.2.1 Personal Influences (PI)

From the analysis of the results, the current research proposes that demographic factors such as the age of the user, gender, head of household, educational level, income, location and household size are potential factors that can influence the adoption and utilisation of biogas technology. From the study, it is argued empirically that these factors can directly or indirectly influence the intention to use biogas technology.

Age factor is an important influence in the usage of technology. Exploring the influence of age in the adoption and utilisation of biogas technology in the province will provide a better understanding of the aspect of the age cohort in order to increase the adoption and utilisation of biogas technology. In several technology adoption studies, particularly in developing countries (Baker *et al.,* 2007), age is a paramount factor that influences decision-making in the adoption of technology. For example, older people may have additional resources that will influence them to adopt capital-intensive technologies than younger ones. There are, however, some technologies where younger people have higher likelihoods of adoption than older people are because the risks associated with new technologies are likely to be accepted by younger people. Young people are also considered to have a long horizon of planning; therefore are more innovative. The study found age as a factor with a positive correlation of statistical significance level of $p < 0.01$.

Gender is another crucial factor, as revealed by the field results when analysing the adoption and utilisation of biogas technology, with established statistical significance of $p < 0.01$.

Gender responsibilities can influence the uptake of the technology in the form of tasks performed among women and men in the energy supply management system. In many organisations, such as families, hierarchical relationships take the form of female domination and male dominance, which allocates some tasks to women, such as food preparation, fuelwood collection, domestic sanitation, waste disposal management and fetching water. Furthermore, women are more involved in the collection of fuelwood than men, particularly in the rural areas. Traditionally and distinctively, the responsibility of managing domestic energy requirements is shouldered by women in many households in the province. Hence, they may adopt a technology, which is expected to reduce their workload, such as the adoption and utilisation of biogas technology. However, women tend to have restricted powers in decision making in households, including new technologies, where males dominate access, ownership, decision making and control as regards to productive resources and this could directly influence decisions regarding investment in technology, such as biogas.

Education is an important factor that needs consideration with respect to the adoption and utilisation of biogas technology in the province. There is a resilient correlation between technology adoption and educational level or status as indicated in the statistical significance ($p < 0.01$). Everything a person needs to know in order to effectively use a technology is defined as technology literacy. Formal education is expected to positively influence decision making with regards to biogas technology adoption and utilisation (Walekhwa *et al.,* 2009). A high education level is considered less conservative, more knowledgeable, informed and exposed to information sources and environmentally aware of the effects of fossil fuels that negatively affect the environment. It is also expected that higher educational levels compared to low-educated levels, will lead to the acceptance of cleaner source of energy, such as the adoption and utilisation of biogas technology.

Income plays a major role the adoption and utilisation of biogas technology. Income is included in the BAUF as one of the Personal Influence (PI) that can directly influence the Intention to Use Biogas Technology (BI). Potentially, income earned could prevent the likely adopter from pursuing the use of biogas technology. For example, low-income earners may not be able to adopt the technology due to the associated cost of installing a biogas digester, even though they have indicated interest in adopting the technology. In most rural areas of South Africa such as Limpopo Province, due to high unemployment rate, the income level is very low, as most of the residents depend on government grants, pensions and even remittance from family members who migrate to work in urban centres. Thus, income is hypothesized as a direct influence on the intention to use biogas technology. Income as a factor was statistically significant at $p < 0.01$ using the logistic regression model. Income also shows a significant relationship ($p < 0.05$) when cross-tabulated with the cost of installing a digester.

Location factors also influences the adoption and utilisation of biogas technology, positively or negatively. If the intended adopter is located in the rural areas, where there are adequate space, the likelihood of adopting the technology is higher when compared to a likely adopter in the urban centre, where there may be space shortages. Rural areas with access to forests where the problem of fuelwood collection is not acute, can also influence the adoption and utilisation of biogas technology, compared to their urban counterparts. In addition, location can also influence access to crucial services, such as credit, loan, technical assistance and even information that may enhance the adoption and utilisation of biogas technology.

Household size can influence the uptake of biogas technology in the province positively. With the household average size range from 4 to 7 members in the province, a large household size could mean sufficient and abundant labour that is required for managing and operating biogas technology. However, it could also mean greater pressure on the lean household resources, thereby making available labour for fuelwood collection. This can limit the need to move to modern and alternative energy source, such as the adoption and utilisation of biogas technology. Household size is therefore hypothesized as an influential factor in the adoption and utilisation of biogas technology, with a statistical significance of $p < 0.05$ but exhibiting a negative association.

7.2.2 Economic and Motivational Influences (EMI)

One of the most important constructs that needs to be investigated and analysed regarding the adoption and utilisation of biogas technology in the Limpopo Province are the Economic and Motivational Influences. The construct comprises of significant factors that are likely to influence the adoption and utilisation of biogas technology.

Perceived benefits in the adoption and utilisation of biogas technology can be defined as the degree to which biogas technology provides functional and non-functional benefits to the household. This is correlated to the trust in achieving benefits and the anticipated outcomes of using biogas technology. The idea, thereof, is to analyse the effect of the perceived advantages of using biogas technology. The Perceived Benefits factors can be classified in two ways; namely, functional and non-functional benefits.

Functional benefits refer to any tangible benefits that the household can acquire from using biogas technology. These benefits are completing the intended task at any time and day from the biogas technology, which include energy supply in cooking meals, water heating and good strategy in addressing waste management. Furthermore, the functional benefits are considered as using the digestate, which is a by-product in biogas production, as agricultural fertilisers, which is a better substitute for synthetic fertiliser in farm ecosystems, especially for households that are engaged in commercial or subsistence farming. As a means for reduction of greenhouse gases and odour emission control from waste decomposition it is also seen as a functional benefit.

Non-functional benefits signify all intangible benefits that the household can gain from using biogas technology. This includes saving costs in buying electricity vouchers, convenience and comfort of using the technology, time saving, independence and reducing the effort of women and children, particularly walking long distances to fetch fuelwood as alternative energy.

Socio-Cultural factors are factors that influence the implementation of the new technology, especially when the new technology relates to lifestyle improvement in the society. In Limpopo Province, there is a deep socio-cultural phenomenon, even at the household level, accordingly indicating the predisposition of 72% of the households regarding the technology. Such phenomenon, within some culture, includes forbidding women from accessing kraals to gather cow dung and forbiding cooking with such. Two influential factors are combined; namely, socio aspects and cultural aspects. Between the two, there is a strong correlation, as one aspect has the power of changing the other. The normal pressure exerted by friends and family members on the intention to use a new technology constitute social influences (Weerakkody *et al.,* 2013). Thus, in literature, several studies have reported that social influences which is denoted by colleagues, family member and friends has a strong impact on the adoption of new technology such as biogas technology.

Cultural influence is defined as the beliefs, behavioural patterns, norms and values of a group of people in a society for specific professions, national or local culture (Leung *et al.,* 2005). Cultural influence is widely investigated and it is argued that cultural norms have a central correlation with biogas adoption and utilisation. Some religions and traditions have stern rules in respect to cleanliness, which to a large extent not connected to humans alone, but also to animal excrement (GTZ, 1999). Such positions can potentially hinder the dissemination, adoption and utilisation of biogas technology. The attitudes and positions of numerous aspects of social and cultural influences in society need to be understood before starting a biogas programme, in order to discover how they can affect the adoption and utilisation of the technology. This framework contends that some important aspects; namely, image, influence of others and resistance can also influence the adoption and utilisation of biogas technology.

Image refers to the perceptions of the household that societal superiority will be afforded them for adopting and using biogas technology. In literature, it is claimed that adoption of new technology, such as biogas, might reflect household familiarity with modern technologies, a high educational level and a high degree of modernism. This phenomenon adds a degree of social value and prestige to the adopter, particularly in rural areas.

The Influence of others: it is widely accepted that the most powerful influence on human behaviour is other people. Social influence runs deeply, as our behaviour is affected by how we feel for others and those we know. In the context of Limpopo Province, is the impact of others is more important, as the society is coherent and interrelated. The interrelationship of friends and family members and even social relationship is so strong that it could affect the decisions of a household to adopt and utilise biogas technology.

Resistance is societal behavioural norm and can greatly affect new technology adoption and utilisation through resisting the changes new technologies can bring which is likely to lead to negative consequences regarding implementing such technology (Watson *et al.,* 1994). One factor considered as a negative factor to the successful implementation of any technology, including biogas technology is resistance to change. Due to trust issues, some households may resist using biogas technology, while others may resist adopting the technology because of uncompromising cultures, which is very influential.

Awareness of the services and functions that any technology can provide to the user is a very essential factor. In the adoption and utilisation of biogas technology, a strong contributing factor is the perceived awareness of the technology by the household in the province. Thus, in intending to promote biogas technology in developing countries, such as South Africa particularly in remote areas such as the Limpopo Province, there is a need for conscious awareness, by making the intended users familiar and aware with the technology. This shows a statistical significant relationship ($p < 0.01$) indicating its importance in the adoption and utilisation of biogas technology. It is assumed from the result analysis of the study that there is a low level of awareness in the province regarding the technology; with 22% to 78%. However, there are various ways in which awareness can be improved, either through community traditional leaders, interactive advertising, mass, print and social media. Fundamentally, social media can play a vital role, by enhancing the adoption and utilisation of biogas technology, by increasing the level of awareness in this regard.

Access to credit is another important factor can affect household intention to adopt and utilise biogas technology, particularly in the former homelands of Limpopo Province. This is because there are few to no financial institutions where households can obtain loans. Thus, due to the low incomes earned by the rural populace, it will be difficult for them to make payments in lump sum that is required for the construction of biogas digesters. Hence, the introduction of credit schemes in the form of soft loans for the populace can motivate their interest in adopting new technologies such as biogas technology. Statistically, this factor revealed a significance ratio of 1.87, as access to credit will enable poor households with the desired interest to adopt the technology.

Livestock ownership is another vital factor from the analysed results that can influence the adoption and utilisation of biogas technology in Limpopo Province, particularly in rural areas. Herds of cattle owned indicates a statistical relationship ($p < 0.01$) by a factor of 1.21 with the adoption of the technology. Animal dung is considered one of the major substrates for the operation of biogas technology particularly in rural areas. Households that own livestock are thus likely be motivated to adopt the technology as one basic material for the functionality of the technology is already available and within reach. Households with livestock using the technology in the province stand at 7% using the technology but not owning livestock either buying or obtaining from neighbours. Furthermore, 79.7% of households without the technology own livestock while 20.3% do not.

Regulations and Policies for using renewable energy should be stated clearly in order to satisfactorily reach the levels of adoption and utilisation of renewable energy, such as biogas technology. Furthermore, setting up clear regulations is emphasised in implementing such technology, in order to encourage households to adopt such technologies. Regulations include terms and conditions for using renewable energy and tax policies. For example, in terms of the national legislation of South Africa, owners of biogas operations that are not connected to the national pipeline gas grid do not have to be licensed but are required to be registered with the National Energy Regulatory of South Africa (NERSA) (DoE, 2017). Although, there are clear regulations and policies in the province that supports the promotion of generating renewable energy, this has however been so slow in implementing.

Previous Experience is a very significant factor that this conceptual framework (BAUF) has included, based on the outcome of the field survey. It is the experiences that households have encountered in the past regarding biogas technology. This framework proposes that the influence of previous experiences can have a strong impact, positively or negatively on future interaction regarding the adoption and utilisation of biogas technology. As in the case of Limpopo Province, there is little previous experiences from the households in the study are due to limited pilot programme that is aimed at promoting and disseminating biogas technology. The Economic and Motivation Influence (EMI), which includes the Previous Experience factor, have a direct influence on all the other factors. This influence will determine all other research factors on the first use of biogas technology and the continued use thereof.

7.2.2 Technical Influences (TI)

In any technological system, there certainly will be technical aspects that are addressed and taken into consideration, in order for the desired goals of using such technology can be achieved as 96% of the households lament about lack of technical assistance or support. The current study concentrated on the theoretical technical aspects that are associated with households' adoption and utilisation of biogas technology that encompasses the application of the technology. Technical influences addressed in this conceptual framework (BAUF) were the following:

Simplicity refers to individual factors that can simplify the adoption and utilisation of biogas technology and makes it easy to use. It has been acknowledged that the easier a technology is to use, the greater the chance of adopting it. This relationship is important particularly with regard to technology such as biogas. As households utilise it, their abilities and skills may significantly differ. Included in simplicity are the following factors:

Biogas stove design is one factor this framework greatly considered as significant, which has not been given attention. In several of the homes surveyed in the province, mostly in the rural households, most meals are prepared with a three-leg-prong pot, which is not compatible with most of the biogas stoves due to the flawed design, and as such hinder household willingness to adopt and utilise the technology. Therefore, in order to accelerate the adoption rate and satisfaction level, cooking stoves should be designed according to the households' requirements, in order to accommodate their cooking utensils, which are mostly three-legged pots.

A biogas description factor indicates how the digester works, the description, application, processes of the technology and how it is used to explain to the intended household. A better understanding is provided through such information. A biogas digester is made up of bricks, sand, cements and iron rods among others. However, the system consists of inlet and outlet tanks, pipes. Providing such tips and methods involved regarding the technology is important, as is helping the households in successfully adopting and utilising the technology.

Technical description is addressing the need for the adoption and utilisation of biogas technology. The technical description forms the visible aspects can affect households' intention and willingness to adopt and use the technology. The technical aspects should show the quality of the technology, from the materials used in constructing the digester and be suitable for people with special needs, such as physical disabilities. This can influence the level of adoption, as lack of such inputs can lead to dissatisfaction and frustration from the intended user.

Technical availability is also considered one of the major factors influencing the adoption and utilisation of biogas technology in the province. The decline in biogas digesters in the province is largely due to technical availability; thus this shows a statistical relationship at $p < 0.05$ but with a negative coefficient of -0.37. Virtually all the households with biogas digesters surveyed complained of technical availability. Households' complaints were in terms of assistance when the need arose such that no personnel is available to render any help with the technology. The households revealed that they only encountered personnel during the period of installing the digesters. However, afterwards, no follow up was made with respect to how the digesters are functioning. Thus, the statistical results indicated a positive correlation between the adoption of the technology and technical availability.

Security is another factor to be considered in the adoption and utilisation of biogas technology. Security implies safeness to use the technology, without causing any bodily harm to the user, the household, or the community at large. In order to intensify the level of adoption and utilisation, the user has to be safe in the process of operating the technology. Thus, households need to be informed about any impending security threats which can arise from the operation of the technology, as such factors are likely to influence household perceptions about the technology.

Trustworthiness plays an important role in helping households overcome any uncertainty and perceived risks involved in the adoption and utilisation of biogas technology. The issue of trust can affect households intention to use any technology. In literature, trustworthiness has been found to be a vital factor in the acceptance of technology. However, there is still inadequate research that has investigated and analysed the influence of trust on biogas adoption and utilisation by households. Trust importance is based on the fact it can be built on first impressions and any shortcoming later can also affect it. In technology, it is difficult to regain trust mostly in a virtual and uncertain environment.

Durability, Reliability and Performance are further factors to be considered in the adoption and utilisation of biogas technology at household level in Limpopo Province. These factors can individually or jointly influences the upsurge of biogas technology. Any technology that cannot guarantee durability from imprecise construction likely stands a smaller chance of adoption. Often, biogas technology is flawed due to imprecise construction, inadequate repair and maintenance. Thus, the technology should be relied upon when preparing meals, either in small or large quantities, even when used for water heating purposes. Performance regarding the technology should guaranteed in terms of cooking duration and be continuous, rather than be seasonal when needed.

7.2.3 Environmental Influences (EI)

Environmental Influences (EI) are important constructs in the BAUF that was developed in the current study. It comprises fundamental factors that are related to households' trust and perceived risk. Included in the factors are the following:

A forest is a paramount factor that affects the adoption and utilisation of biogas technology in Limpopo Province particularly in the rural areas of the province. From the results, with an odd ratio of 0.68 and a negative association coefficient of -0.003, and despite walking long distances into the forest and carrying heavy headload of fuelwood, unrestricted access to the nation's forest where households can easily harvest fuelwood for domestic purposes poses a threat to the uptake of the technology. Due to this alternative energy source, households are sometimes reluctant to try out new technology. Uncontrolled fuelwood harvesting can also lead to forest degradation and worsen the soil conditions, exposing it to threats of soil erosion. It also affects the forest cover in capturing the emissions of greenhouse gases through carbon sinking by the trees. Furthermore, the adoption and utilisation of biogas technology can aid in soil protection, as the roots of trees help in stabilising the soil, thereby reducing surface runoff, while gradually regenerating the forest (GTZ, 1999).

Water Availability is considered a significant factor in the adoption and utilisation of biogas technology. The substrate for biogas operation is mixed with same proportion of water, in order to support methane production in the process of anaerobic digestion in the sceptic tank. Though the analysis of the result indicated that water is available within a walking distance of 20-30 minutes from the household, most households particularly those in the remote part of the province, are still faced with acute shortages and irregular supply of water. Thus, availability and close access to water supply will influence the degree of household level of adoption and utilisation of the technology.

Climatic Conditions is another factor that affects the adoption and utilisation of biogas technology. Although, the province lies in the subtropical region, the unpredictable weather characteristics due to the intersection of the Tropic of Capricorn as daily temperatures can sometimes go extremely hot or cold. These affect the regular production of gas from the digester. The production of biogas is suitable where average ambient temperature ranges above 15 ^{0}C. Anaerobic digestion decreases significantly below 8 ^{0}C. In addition, the process is sensitive to variations in temperature of more than 3 ^{0}C; temperature variation, therefore, needs to be kept at a limited range, in order to ensure a steady production of the gas. In high altitudes or cold weather, biogas production decreases because it affects the hydraulic retention time (HRT). Furthermore, its seasonality influences the adoption and utilisation of biogas technology. The technology functionality should cut across dry or wet season, in terms of reliability and thus should be season-friendly. Temperature as a factor, as reported by 64% of the households hinders their ability to utilise the technology.

Critical factors and support systems refers to situations where awareness advocacy stands out as the most overriding factor that can help facilitate the adoption and utilisation of biogas technology in the province, particularly at household level. Most households do not have enough awareness about the technology, particularly its benefits. However, with proper awareness advocacy, all issues pertaining to the technology in terms of education, the perceived benefits will be addressed sufficiently. Through adequate awareness campaigns, other stumbling factors such socio-cultural phenomena can be eradicated or at least be brought to the minimum. After appropriate awareness advocacy and campaigns, support systems such as technical assistance should be well introduced to the communities, in order to solve problems relating to the digesters. This can be achieved through organising training for the local artisans involved in the construction of the digesters as well as interested households who may wish to learn. Additionally, subsides, loans and credits should be made available to households that shown a strong desire to acquire the technology but are financially handicapped.

7.3 Summary

This chapter focused on the development of a conceptual framework that will enhance the adoption and utilisation of biogas technology, using the Limpopo Province as a case study. The parameters for the development of this framework was informed from the field survey. They were objectives one, two and three. Significantly, some constructs involved in the analysed framework are imperative and are supported in the literature; hence, they will be incorporated into the present framework. The primary objective of the framework is to convey the basic functionality and fundamental principles, which the system represents. In addition, it was developed in such a way that it provides an easy understanding and interpretation of the system for the user of the framework. The rationale of the framework, when properly implemented, is to enhance understanding of the representative system, and efficiency conveyance of the system details between the stakeholders. Using the conceptual framework, incorrect requirements and the likelihood of unclear, incomplete and inconsistency are minimized. The next chapter, which is the last chapter of this thesis, presents the conclusion and recommendation of this study.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The key objective of this study was to develop a framework that will enhance the adoption and utilisation of biogas technology as an alternative source of energy for emission reduction of GHGs in Limpopo Province of South Africa. The study was conducted in Limpopo Province, where there are few operational biogas plants. Two sampling procedures were used; namely, purposive sampling technique for households with biogas digesters, and simple random technique, for households without biogas digesters. The objectives of the study were to evaluate household levels of biogas awareness and perceptions towards the adoption of the technology, determining the correlating factors influencing the sustainable adoption and utilisation of biogas technology in the rural areas of Limpopo Province and estimating the amount of greenhouses emitted from fuelwood use in the study area. These were used as a yardstick in developing a comprehensive conceptual framework for the adoption and utilisation of biogas technology in achieving the main objective.

Literature on the adoption of biogas technology is expanding and increasingly. Thus, in the field of biogas technology, this thesis contributes to the existing body of literature. Based on the study findings, it can be concluded that the adoption and utilisation of biogas technology in the province is viable. However, the level of adoption and utilisation remains low; hence, affecting the sustainability of the technology. The empirical results conform to the hypotheses which guided the study, that multiple factors influence the adoption and utilisation of biogas technology and that users' level of awareness and perceptions play an important role in a household's choice of energy sources in Limpopo Province. The study findings have some important policy implications that point to some policy interventions that could support and encourage the adoption and utilisation of the technology. The following are conclusions based on the thesis findings:

In any given technology, the awareness and perceptions of the users have been found to play an important role in the adoption and utilisation of the technology. Households awareness and perceptions of biogas technology were investigated in order to get a deeper insight into the barriers to its adoption and utilisation. The majority of respondents indicated that they are not aware of the technology, which could be attributed to the means through which the technology is disseminated in the province. Most households claimed they had heard or gained a little knowledge about the technology from neighbours who have the digesters.

Furthermore, the calculated results from the ranked data of users and non-users of the technology and tested using the Spearman rank correlation coefficient indicated that there is a significant relationship, at $p < 0.05$, with a calculated value of 0.68, between the technology perception and adopting the technology. Income earned by households against the cost of building a digester were also tested using the chi square, and the results indicated a significant relationship $p < 0.05$, implying that income earned by households is strongly tied to the adoption of the technology.

Drawing from the field survey, the level of adoption and utilisation of the technology remains very low. Identified factors that can positively promote the technology development in the province include income level, educational level, gender, household involvement in crop production, distance to fuelwood collection and source, household size, availability of loans, credit and subsidies, water availability, number of cattle owned, awareness of the technology, age, technical availability and knowhow. On the other hand, the utilisation of the technology is mostly affected by socio-cultural phenomena, technical and environmental conditions. The Logistic regression was used to statistically test the significance of these explanatory variables, and it was found that eight of these variables were positively correlated at $p < 0.01$, while the other four were also significant, at $p < 0.05$, but were negatively correlated as factors leading to the adoption of biogas technology. Therefore, the study established that socio-economic determinants factors are key in the adoption of the technology, whereas socio-cultural, technical and environmental factors influence the utilisation.

The study also indicated that fuelwood consumption in households with and without biogas digester stands at 13 kg and 19 kg daily, with CO_2 of 21.47 t and 31.37 t, CH_4 0.10 and 0.13 t, N_2O 0.00065 t and 0.00094 t respectively. Using the average number of four free grazed herds of cow per household and available dung of 20 kg, and thermal efficiency of 55%. The energy output from the biogas digester stands at 1.95 kWh day $^{-1}$ compared to the use of fuelwood with a thermal efficiency of 13%; thus, requiring 5.25 kg of fuelwood to burn, in order to generate 1.95 kWh day $^{-1}$ of energy as biogas. The adoption and utilisation of biogas technology in the province can help mitigate against the emission of greenhouse gases from the combustion of fuelwood there by paving the way for clean energy option.

8.2 Contribution to knowledge

As previously stated, this conceptual framework was developed based on common theories and models used in the acceptance of technology that have been utilised in most adoption studies as well as from empirical results obtained from the field survey. In investigating and analysing key factors in order to determine which can influence a household's adoption and utilisation of biogas technology in Limpopo Province, the current research developed a comprehensive conceptual framework (BAUF) that can be used as a yardstick for future work. A number of factors that are significant were critically analysed in these common theories and models. These were incorporated in this conceptual framework with a wider insight. The perceived benefits in BAUF, for example, are similar to the perceived usefulness concept in Relative Advantages in Diffusion of Innovation (DOI) and to the Technology Acceptance Model (TAM) (Rogers, 2003; Davis et al., 1989) but with a broader interpretation. Furthermore, the simplicity factor is more comprehensive than the Ease of Use in the Effort Expectancy in the UTAUT and the TAM.

However, in this conceptual framework, there are several factors that are important and which were not previously addressed in most biogas adoption studies, mainly those conducted in developing countries. This is because, common technology acceptance model are utilised by most biogas adoption studies. Furthermore, many fundamental factors were originally lacking. Added to this conceptual framework are independent factors that are important such as the influences of Previous Experience, Cultural, Awareness, Trustworthiness, Security, Regulations and Policies. This current research proposed and developed a broad and simplified framework in a manner that provides a robust scientific conceptual framework for analysing the interaction of biogas technology. Furthermore, the strength of the BAUF is that it is a universal framework, meaning it can be utilised in provinces other than Limpopo Province, as well as in other countries other than South Africa. The framework can also be adapted and used in the analysis of adoption and utilisation of diverse interactive technological systems and numerous service applications because the influential factors that are decisive in such analysis have been addressed. This study also offers a bridge between the technical development and the adoption and utilisation of the technology.

A number of factors that are significant have also been included in the conceptual framework taken from extensive research of technology acceptance theories and models in existing literature. Other empirical results from the field survey that are crucial in the adoption and utilisation of biogas technology that are more appropriate and comprehensive have also been developed and included in the current study. Thus, it is tailored based on principle of fit for purpose instead of the existing unimodal approach for all settings. The BAUF is a simple representation of complex reality and was validated based on other competing frameworks or model such as the TRA, TAM, DOI, and UTAUT. The Biogas Adoption and Utilisation Framework (BAUF) can be fully tested, and validated by different stakeholders in the biogas industry, in order to explore and determine the direct and indirect influences of the constructs on the actual biogas technology adoption and utilisation in South Africa.

8.3 Recommendations

The following are recommendations based on the study findings, which are central to the critical factor and support systems. An example of an approach by government in providing the digesters to households, as a pro-poor strategy, may be in the form of credit, loans or subsidies. This may increase households' commitment to use the technology. Alternatively, as part of cost-sharing, the government may perhaps demand potential adopters of the technology to provide building materials, such as gravel, stones and sand, for the construction of the digester. Households may also excavate pits where the digester will be situated. Technical support should be provided and, where possible, routine visits and follow-ups should be made to households with biogas digesters, to check and rectify any problem(s) in the digester. Re-designing of cooking stoves to accommodate most of the cooking pots used in the households, for preparing local meals, will improve the level of adoption and utilisation of biogas technology. Thus, training and re-training of personnel on the operation and maintenance of the technology is needed.

This study also revealed that there are various factors that are indispensable elements underlying the adoption and utilisation of biogas technology in Limpopo Province at households level. Some appropriate polices were drawn based on the study findings and these highlight the necessity of promoting programmes designed for this technology country-wide, in the study area in particular. Firstly, in the absence of a top-down approach from government, and considering that the technology has benefits both in environmental and economic terms, it is necessary for the government to provide some monetary assistance. This can be in the form of subsidies, loans and credit to prospective adopters of the technology in order to invest in the technology and thus lessen their economic burden. This method has been in practised in many developing countries. It can also be implemented in South Africa with the assistance of commercial banks, rural development agencies, municipal councils, the private sector and savings and credit cooperative league of South Africa. Caution must, however, be exercised by financial institutions involved by understanding that borrowers are not the same; thus, in order to obtain the most impact from the loans, priority should first be given to those in additional need of capital.

To overcome socio-cultural limitations, there is a need for a comprehensive and intensive educational campaigns to promote the benefits and awareness about the technology. Therefore, there is a need to pinpoint the accomplishment of biogas technology in the province and the country at large. This can be achieved through sharing of information and awareness, and where possible individual testimonies. The testimonies could be in the form of satisfied users of the technology telling others about the benefits of using the technology. It is, however, imperative to truthfully inform the potential adopters the precise information required to accurately and successfully operate the digester without exaggerating the benefits. This could be successfully achieved through different mechanisms of propaganda, such as mass media, publication and circulation of simple but well-illustrated booklets and posters.

The correlation regarding education and adoption, and utilisation levels of biogas technology is very crucial as a factor of household involvement in the technology. Furthermore, it has long been held that education is imperative in the dissemination and development of any technology. The policy implication from the study results maintain that the educational level increases the probability of household adoption of the technology. The educational level can be achieved through an enhanced increase in enrolment rate at schools and more educational facilities should be provided at technical and vocational education and training (TVET), while the present infrastructure is strengthened. Education is central in the transfer process of biogas technology. Therefore, the earlier the technology is taught, the better and the faster the process of planning and development. The income earned by households was also found to increase the chances of biogas adoption and utilisation in the study area. The result implies that income opportunities and earnings should be created and can be achieved through patronage by large retail stores in households engaged in subsistence crop production. The government can also contribute by creating small and medium-scale enterprises that can engage an income for rural dwellers.

Access restriction to fuelwood collection, particularly in government-reserved forests, should be fully implemented and adhered to. Forests are easily accessed by households, whereby trees are cut down for fuelwood. This is because of lack of enforcement of environmental laws. Forests are of enormous environmental importance because of the vital role they play. In the study area, the vegetation was in a state of decline due to over-exploitation and over-utilisation of the forest resources. The government is supposed to conserve forests using the law as a tool. Environmental legislations, when enforced, will limit or prevent easy access to the forests. Furthermore, the South Africa National Environmental Management Act 107 of 1998 and the Environmental Conservation Act 10 of 2004 laid-down environmental legislations, if obeyed, will help in conserving the remaining forests.

In Limpopo Province, the institutional framework for the dissemination of biogas technology is weak. Therefore, there is a need, at grassroots level, to go beyond the socio-economic characteristics of households, and create an enabling support programme for adopters of biogas technology. This can be achieved through enhanced infrastructural services, such as technical support. After installing biogas digesters, the government is hardly available to provide the technical services or assistance required to maintain the digester. The absence of this support creates an ownership gap, as households view the digesters as externally owned; hence, necessitating support to continuously maintain them. Thus, altogether, the technology breaks down or it is abandoned. For instance, an umbrella body such as the Southern African Biogas Industry Association (SABIA) could be tasked with stimulating interaction and coordination between households, biogas stakeholders, as well as public and research through bottom-up approaches. This could inevitably create a broad network for the exchange of experiences between all the parties involved in the advancement of the technology.

8.4 Practical Implications of the study

The study findings have a number of very important practical implications that are relevant for future adoption and utilisation studies on renewable technologies in Limpopo Province, South Africa and other countries, particularly developing countries that will opt for the advancement of similar technology. The study faced some challenges, which include the following:

The availability of biogas digesters is decreasing amongst households, as many of them are poorly run. The popularisation and use of other forms of commercial energy and decline in subsistence farming within the households are some of the contributing factors. Many of the digesters are much underutilised. This development can be attributed to poor technical expertise, which has resulted in low combinative-utilisation levels of the technology in meeting their energy need and well as increasing their subsistence agricultural output. There is, thus a need for improved incentives and policies that will strengthen the technology. Presently, the regulations, policies and standards for the construction of large to medium-scale digesters are still behind industrial standards. As noted from the findings, there is a shortage of technical assistances. This has resulted in poor designs, construction and maintenance of the digesters, which poses a challenge for the adoption, and utilisation of the technology.

Biogas fermentation takes place under normal temperatures. These rely mainly on air temperatures and natural ground. However, the digesters on their own do not offer any measures to raise the temperature. Low conversion and low efficiency of feedstock in the digesters are a result of the low temperatures. These, thus, affect the generation and production of gas. Due to the temperature fluctuations, there is sometimes too much gas produced on summer days, while little is produced on winter and cloudy days; hence creating seasonal shortages and wastage. Other challenges include the dearth of reliable information regarding potential benefits of the technology, lack of legislation, academic research and commercial infrastructure of the technology in the province. In practice, there is a dearth of knowledge regarding biogas technology and ownership responsibilities among users.

8.5 Areas of further research

On future work, due to the peculiarities of rural settings, important issues of research should explore more on the technical, economic, socio-cultural, environmental and logistic feasibility of the use of the technology from a local context and perspective. The problems associated with biogas technology are multidimensional, hence future work should approach it from a multidimensional viewpoint, in order to deal with the evidence-based problems, to support such a policy. Research should focus on pilot studies and full-scale experiences at the levels where all the stakeholders will fully understand what it takes to efficiently and gainfully use the technology. Furthermore, research at Universities are often considered too theoretical. Thus, there is a need for a practical demonstration in respect to the technology. Research on further work should also identify users' needs and local conditions, in order to determine the type of biogas design that is best for the area. This can positively improve the effective use of the technology, as it is tailored to the users' needs. Finally, more research is required in the area of fermentation of alternative substrate that can stand seasonal variation of temperature due to weather variability. Furthermore, the conceptual framework can be developed into an operationalised model and can be converted into a mathematical model. This is because the structural equation of the framework was not done due to the socio-economic and environmental parameters which often times are contextually dependent and spatially varied.

8.6 Limitations of the study

The major sources of information relied upon for the current study were elicited primary and secondary data. Thus, the results need to be understood from this context and perspective. However, the conclusions of the study could be extended to other areas exhibiting similar socio-economic characteristics, with some adjustments. Finally, the findings cannot be generalised to the whole country, as only a single province was used in the study. Thus a supplementation of the findings with further studies is suggested, due to the peculiarities and differences of specific areas. Although, the framework was not fully validated, but the choice of components was informed and grounded by empirical evidence based on field surveys, hence reliable empirical research was done.

References

Aalbers, R., der Heijden, E., Potters, J., van Soest, D. and Vollebergh H. 2007. Technology adoption subsidies: an experiment with managers. Discussion paper 082/3. Amsterdam: Tinbergen Institute.

Aaron, J. and Muellbauer, J. 2006. Estimates of Household Sector Wealth for South Africa, 1970 – 2003. *Review of Income and Wealth,* 52(2): 285-308.

Abadi-Ghadim, A.K. and Pannell, D.J. 1999. A Conceptual Framework of Adoption of an Agricultural Innovation**.** *Journal of Agricultural Economics,* 21(2): 145- 154.

Abbas, T., Ali, G., Adil, S.A., Bashir, M.K. and Kamran, M.A. 2017. Economic analysis of biogas adoption technology by rural farmers: The case of Faisalabad district in Pakistan. *Renewable Energy,* 107:431-439.

Adeola, I. E., Hermish, L. and Emphraim, O. 2009. *Rethinking Biomass Energy in Africa,* Berlin: Association of German Development NGOs (VENRO).

Akinbami, J.F.K., Ilori, M.O., Oyebisi, T.O., Oyebisi, I.O, and Adeoti, O. 2001. Biogas energy use in Nigeria: current status, future prospects and policy implications. *Renewable and Sustainable Energy Reviews,* 5:97–112.

Akpinar, A., Kömurcu M.I., Kankal M., Özolcer I.H. and Kaygusuz K. 2008. Energy situation and renewables in Turkey and environmental effects of energy use. *Renewable and Sustainable Energy Reviews,* 12: 2013-2039.

Amigun, B. and von Blottnitz, H. 2010. Capacity-cost and location-cost analyses for biogas plants in Africa. *Resource Conservation and Recycling,* 55: 63-73.

Amigun, B. and von Blottnitz, H. 2007. Investigation of scale economies for African biogas installations. *Energy Conversion and Management,* 48: 3090-3094.

Amigun, B., Musango, K.J. and Stafforda W. 2011. Biofuels and sustainability in Africa. *Renewable and Sustainable Energy Reviews,* 15(2): 1360–72.

Amigun, B., Sigamoney, R. and von Blottnitz H. 2008. Commercialization of biofuel industry in Africa: a review. *Renewable and Sustainable Energy Reviews,* 12: 690–711.

Anderson, B.F. 2002. *The Three Secrets of Wise Decision Making.* Portland: Single Reef Press.

Anin, F.D.K. 1999. A Note on the Adoption of Soil Conservation Measures in North Province of South Africa. *Journal of Agricultural Economics,* 50(2): 336-345.

Arnold, J.E., Kohlins, G. and Persson, R. 2006. Woodfuel, livelihoods and policy interventions: changing perspectives. *World Development,* 34(3): 596-611.

Arthur, R., Baidoo, M. and Antwi, E. 2011. Biogas as a potential renewable energy source: A Ghanaian case study. *Renewable Energy,* 36: 1510-1516.

Ashira, R. and Rasheed A. 2017. Current status, hurdles and future prospects of biogas digestion technology in Africa. *Renewable and Sustainable Energy Reviews,* 67: 1162–1179.

Awan, A.B. and Khan, Z.A. 2014. Recent progress in renewable energy – Remedy of energy crisis in Pakistan. *Renewable and Sustainable Energy Reviews,* 33: 236-253.

Awino, W.O. 1999. Solar ovens in Africa: Status, constraints and strategies. In SEASAE proceedings: *Agricultural Engineering, Environment and Development:* 251–253.

Baidu-Forson, J. 1999. Adoption of soil and Water Conservation Practices in the Sudan-Sahel zone. Constrains and incentives. *Journal of Agricultural Economics,* 21(3): 231-239.

Bajgain, S.S. 2005. The Nepal biogas support programme: a successful model of public priv ate partnership for rural household energy supply. Kathmandu, Nepal: Ministry of Foreign Aff airs (The Netherlands), SNV and Biogas Sector Partnership—Nepal.

Baker, E., Al-Gahtani, S. and Hubona, G. 2007. The effect of gender and age on new technology implementation in a developing country*. Information Technology and People,* 20: 352-375.

Bartz, F.J., Peter, K.J. and Janssen, W. 1999. Influence of Technology Characteristics on the Rate and Speed of Adoption. *Agricultural Economics,* 21(2): 121 -130.

Bekele, W. and Drake, L. 2003. Soil and water conservation decision behavior of subsistence farmers in the eastern highlands of Ethiopia: a case study of the Hunde-Lafto area. *Ecological Economics,* 46: 437-451.

Bensah, E.C. and Brew-Hammond, A. 2010. Biogas technology dissemination in Ghana: history, current status, future prospects, and policy significance. *International Journal of Energy and Environment.* 1(2): 277-294.

Berkele, D.B. and Verburg, P.H. 2011. Sensitising rural policy: assessing spatial variation in rural development options for Europe. *Land Use Policy,* 28: 447- 459.

Betül, O. 2017. Biogas energy opportunity of Ardahan city of Turkey. *Energy*, 139: 1144-1152.

Boahene, A. 2008. The challenge of deforestation in tropical Africa: Reflections on its principal causes, consequences and solutions. *Land Degradation and Development,* 9: 247-258.

Boden, T.A., Marland, G. and Andres, R.J. 2011. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Bond, T. and Templeton, M.R. 2011. History and future of domestic biogas plants in the developing world. E*nergy for Sustainable Development* 15: 347–354.

BP, 2014. Statistical Review of World Energy, Excel workbook of historical data. London.

Broadhead, J., Bahdon, J. and Whiteman, A. 2001. *Past trends and future prospects for the utilization of wood for energy, in Global Forest Products Outlook Study (GFPOS)*. Food and Agricultural Organization (FAO): Rome.

Brown, S., Gillespie, A.J.R. and Lugo, A.E. 1999. Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science*, 35:881-902.

Bruijnzeel, L. A. 2004. Hydrological functions of tropical forests: not seeing the soils for the trees? *Agriculture, Ecosystems and Environment,* 104: 185-228.

Burton, M., Rigby, D. and Young, T. 1999. Analysis of the Determinants of Adoption of Organic Horticultural Techniques in the UK. *Journal of Agricultural Economics,* 50 (1): 47-63.

CBRI (Chengdu Biogas Research Institute), 1989. *Biogas Technology in China*. Chengdu, China.

Census of Botswana 2001, Population and Household Census, Census Unit, Botswana.

Census of India, 2001, available from www.censusindia.net (Accessed 21 June 2018).

Chan, F.T.S., Chan, M.H. and Tang, N.K.H. 2000. Evaluation methodologies for technology selection. *Journal of Materials Processing Technology,* 107: 330-337.

Charters, W.W.S. 2001. Developing markets for renewable energy technologies. *Renewable Energy,* 22(1-3): 217-222.

Cheng, S., Li, Z., Mang, H.P., Huba, E.M., Gao, R. and Wang, X. 2014 Development and application of prefabricated biogas digesters in developing countries. *Renewable and Sustainable Energy Reviews,* 34: 387–400.

Chomitz, K. M., Buys, P., Luca, G. D., Thomas, T. S. and Wertz-Kanounnikoff, S. 2007. *At loggerheads? Agricultural expansion, poverty reduction and environment in the tropical forests.* World Bank Policy Research Report. Washington DC: World Bank.

Collins, O., Pindozzi, S., Faugno, S. and Boccia, L. 2013. Development of bioenergy technologies in Uganda: A review of progress. *Renewable and Sustainable Energy Reviews,* 18: 55-63.

Cramb, R.A., 2003. Processes affecting the successful adoption of new technologies by smallholders. *In:* Hacker, B. (Ed). *Working with Farmers: The Key to the Adoption of Forage Technologies*, pp.11-22. ACIAR Proceedings No. 95. Canberra: Australian Centre for International Agricultural Research technologies. http://www.idrc.ca/en/ev-85061-201-1-DO_TOPIC.html (Accessed 04 November 2018).

Creswell, J.W. 2013. Qualitative Inquiry and Research Design: Choosing among Five Approaches (3rd Ed.). Thousand Oaks, CA: SAGE.

Damm, O. and Triebel, R. 2008. A synthesis report on biomass energy consumption and availability in South Africa. Johannesburg: Programme for basic energy and conservation ProBEC and LHA Management Consultants.

Davis F.D. 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly,* 319-340.

Davis, D., Bagozzi, P. and Warshaw R. 1989. User Acceptance of Computer Technology: A Comparison of Two Theoretical Models. *Management Science,* 35: 8.

Department of Energy, 2015. State of Renewable Energy in South Africa. Pretoria: Department of Energy.

Department of Water Affairs and Forestry. 2007. Free basic water implementation strategy: Consolidating and maintaining, Version 4. Pretoria: South Africa.

Department of Energy, 2013. A survey of energy-related behaviour and perceptions in the residential sector. Pretoria: South Africa.

Department of Energy, 2013. IEP planning report overview of universal energy access strate gy. (http://www.energy.gov.za/files/IEP/Mpumalanga/Overview-of-Universal-Energy-Access-Strategy.pdf, (accessed 18 June 20118).

Department of Energy, 2017. Energy Annual Report 2016-17. http://www.energy.gov.za/files/Annual%20Reports/DoE-Annual-Report-2016-17.pdf (accessed 16 June 2018).

Enger, H.M. and Smith, H.I. 1995. *Environmental Science, A study of interrelationship.* London: John Wiley.

Erdogdu, E. 2008. An expose of bioenergy and its potential and utilization in Turkey. *Energy Policy,* 36: 2182-2190.

Eseonu, C.I. and Egbue, O. 2014. Socio-cultural influences on technology adoption and sustainable development. In *Proceedings of the Industrial and Systems Engineering Research Conference, Montreal, QC, Canada* (pp. 2711-2717).

Eshete, G., Sonder, K. and ter Heegde F. 2006. Report on the Feasibility Study of a National Programme for Domestic Biogas in Ethiopia for SNV-Ethiopia. Addis Ababa.

Ezzati, M., Kammen, D. M. and Mbinda, B. M. 2002. Comparison of emissions and residential exposure from traditional and improved cook stoves in Kenya. Environmental Science and Technology (ES&T).

FAO, 1996. SD Environment: A system Approach to Biogas Technology**.** Training Manual for extension. http://www.fao.org (Accessed 24 October 2018).

FAO. 2016. Sustainable forest management. Rome: http://www.fao.org/forestry/ sfm/en/. (Accessed 24 October 2018).

Florentino, H. 2003. Mathematical Tool to Size Rural Digesters. *Scientia Agricola*, 60(1): 185-190.

Floyd, C., Harding, A., Paudel, K.C., Rasali, D.P., Subedi, K. and Subedi, P.P. 2003. Household adoption and the associated impact of multiple agricultural technologies in the western hills of Nepal. *Agricultural systems,* 715–738.

Food and Agriculture Organisation, 2017. Forest and Energy in Developing Countries. [Online]. Available: ⟨http://www.fao.org/fileadmin/user_upload/rome2007/docs/Forests%20and%20energy.pdf⟩ (Accessed 23 April 2018).

Food and Agriculture Organization 2006. East Africa Spatial Analysis of Woodfuel Production and Consumption Patterns in Selected African Countries. Rome.

Food and Agriculture Organization of the United Nations, 2010. Criteria and indicators for sustainable woodfuels. Rome.

Food and Agriculture Organization, 2004. Unified Bioenergy Terminology, Rome

Food and Agriculture Organization, 2009. State of the World's Forests. Rome

Garson, G.D. 2008. Logistic Regression: Stat notes from North Carolina State University http://www2.chass.ncsu.edu/garson/PA765/logistic.html; [Accessed 17 June 2018].

Gautam, R., Baral, S. and Herat, S. 2009. Biogas as a sustainable energy source in Nepal: Present status and future challenges. *Renewable and Sustainable Energy Reviews* 13: 248-252.

Gebreegziabher, Z. 2007. Household fuel consumption and resource use in rural- urban Ethiopia. PhD thesis. Wageningen, the Netherlands: Wageningen University.

Geist, H.J. and Lambin, E.F. 2002. Proximate causes and underlying driving forces of tropical deforestation. *BioScience,* 52: 143-150.

Ghafoori, E. and Flynn P. C. 2007. Optimizing the Size of Anaerobic Digesters. *Transactions of the ASABE*, 50(3): 1029-1036.

Ghimire, P.C. 2008. Trainee's Manual prepared for National Biogas Programme. www.snvworld.org (Accessed on 25 February 2018).

Ghimire, P.C. 2013. SNV supported domestic biogas programmes in Asia and Africa. *Renewable Energy* 49: 90-94.

Ghosh, R. and Bhattacherjee, S. 2013. A review study on anaerobic digesters with an Insight to biogas production. *International Journal of Engineering Science Invention,* 2: 8–17.

Gitonga, S. 1997. Biogas promotion in Kenya: a review of experience. Nairobi: Intermediate Technology.

GTZ (German Technical Cooperation), 1999. Biogas Digest Volume I: Biogas Basics project Information and Advisory Service for Appropriate Technology (ISAT). Germany: GTZ; 1999.

GTZ (German Technical Cooperation). 2016. Estimating the Biogas Potential for Electricity Generation from the Agro-Waste Industry. A Resource Assessment for South Africa. Germany: GTZ.

Guta, D.D. 2014. Effect of fuelwood scarcity and socio-economic factors on household bio-based energy use and energy substitution in rural Ethiopia. *Energy Policy,* 75:217-227.

Hall, D.O., Rosillo-Calle F. and de Groot P. 1992. Biomass Energy, Lessons from Case studies in developing Countries. *Energy Policy,* 20(1): 63-73.

Hamilton, D.W. 2014. Anaerobic digestion of animal manures: types of digesters. Oklahoma Cooperative Extension Services, 1–4 BAE-1750.

Harris, P. 2005. *Beginners Guide to Biogas*. The University of Adelaide, Adelaide http://www.ees.adelaide.edu.au (Accessed 14 February 2017).

He, P.J. 2010. Anaerobic digestion: an intriguing long history in China. *Waste Management,* 30(4): 549–50.

Hill, D.T. and Bolte, J.P. 2000. Methane production from low solid concentration liquid swine waste using conventional anaerobic fermentation. *Bioresource Technology,* 74(3): 241-247.

Huysamen, G. 2004. *Methodology for the social and behavioural sciences.* South Africa: International Thomson Publishing.

Inayatullah, J. and Waqar, A. 2018. Willingness of rural communities to adopt biogas systems in Pakistan: Critical factors and policy implications. *Renewable and Sustainable Energy Reviews,* 81:3178–3185.

Iniyan, S. and Jagadeesan T. R. 1997. A Comparative Study of Critical factors influencing the Renewable Energy Systems Use in the Indian Context. *Renewable Energy,* 3: 299- 317.

International Energy Agency 2017, *World Energy Outlook 2010*, OECD/IEA, Paris.

International Energy Agency 2014, *World Energy Outlook 2014*, OECD/IEA, Paris.

International Energy Agency, 2004. Biofuels for Transport: An International Perspective. OECD/IEA, Paris. ⟨http://www.cti2000.it/Bionett/All 2004 004%20IEA%20biofuels%20report.pdf⟩ (Accessed 28 September 2018).

IPCC, 1994. IPCC Guidelines for National Greenhouse Gas Inventories, vols. I, II and III. Intergovernmental Panel on Climate Change, United Nations Environment Program, World Meteorological Organization, Organization for Economic Co-operation and Development and International Energy Agency.

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories, vols. I, II and III. Intergovernmental Panel on Climate Change, United Nations Environment Program, World Meteorological Organization, Organization for Economic Co-operation and Development and International Energy Agency.

IPCC, 2016. Climate Change 2015: The Science of Climate Change. Summary for Policymakers. IPCC, Working Group I, Bracknell, United Kingdom.

IPCC. 2011. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change.

Ivan, F.S., Nathalia, D.B.V., Luís, G., Regina, M. and Geraldo, L.T. 2018. Assessment of potential biogas production from multiple organic wastes in Brazil: Impact on energy generation, use, and emissions abatement. *Resources, Conservation and Recycling,* 131: 54–63.

Jannuzzi, G. and Sanga, G. 2004. “LPG subsidies in Brazil: an estimate”, *Energy for Sustainable Development*, 8: 3.

Jorgensen, P.J., 2009. *Biogas-Green Energy*. Denmark: Digisource.

Kabir, H., Yegbemey, R.N. and Bauer, S. 2013. Factors determinant of biogas adoption in Bangladesh. *Renewable and Sustainable Energy Reviews,* 28:881-889.

Kalineza, H.M.M., 1999. Factors Influencing the Adoption of Soil Conservation Technologies in Tanzania. A case Study in Gairo: Proceedings of FoA, *Sokoine University of Agriculture,* 4: 76-84.

Kammen, D. M. 1999. Bringing power to the people. *Environment,* 41 (5): 10–41.

Karekezi, S. 2002. Renewables in Africa — meeting the energy needs of the poor. *Energy Policy,* 30: 1059–1069.

Katuwal, H. and Bohara, A.K. 2009. Biogas: a promising renewable technology and its impact on rural households in Nepal. *Renewable and Sustainable Energy Reviews*, 13: 2668–2674.

Kebede, Y., Gunjal, K. and Coffin, G. 1990. Adoption of new technologies in Ethiopian agriculture: the case of Tegulet-Bulgga, Shoa province. *Agricultural Economics,* 4: 27–43.

Kgathi, D.L and Mlotshwa, C.V. 1994. Utilisation of fuel wood in Botswana: Implication for energy policy. Nairobi: AFREPREN.

Kituyi, E., Marufu, L., Huber, B., Wandiga, S.O., Jumba, O.I., Andreae, M.O. and Helas, G. 2001. Biofuels consumption rates in Kenya. *Biomass and Bioenergy,* 20: 83–99.

Kohlins, G. and Parks, P. J. 2001.Spatial variability and disincentives to harvest. *Land Economics,* 77 (2): 206-218.

Kollár, B. 2014. Credit Value at Risk and Options of Its Measurement. 2nd International Conference on Economics and Social Science (ICESS). Information Engineering Research Institute. *Advances in Education Research,* 61:143-147.

Krippendorff, K. 2004. *Content analysis: An introduction to its methodology. Second Edition*. Thousand Oaks, CA: Sage.

Kumar, A. and Sharma, M.P. 2014. GHG emission and carbon sequestration potential from MSW of Indian metro cities. *Urban Climatology,* 8: 30–41.

Kuo, B.C., Roldan-Bau, A. and Lowinger, R. 2015. Psychological Help-Seeking among Latin American Immigrants in Canada: Testing a Culturally-Expanded Model of the Theory of Reasoned Action Using Path Analysis. *International Journal for the Advancement of Counselling,* 37(2)179-197.

Lamlom, S. H. and Savidge, R. A. 2003. A reassessment of carbon content in wood: variation within and between 41 North American species. *Biomass and Bioenergy*, 25(4): 381-388.

LEDET, 2013. Limpopo Green Economy Plan - Including Provincial Climate Change Response, Polokwane: Limpopo Department of Economic Development, Environment & Tourism. Polokwane.

Lehutová, K. 2011. Application of Corporate Metrics method to measure risk in logistics. *International Scientific Conference in Computer systems aided science industry and transport,* 2209-2213.

Leung, K. Bhagat, R.S., Buchan, N.R., Erez, M. and Gibson, C.B. 2005. Culture and international business: recent advances and their implications for future research. *Journal of International Business Studies,* 36(4): 357-378.

Lewis, J.J., Hollingsworth, J.W., Chartier, R.T., Cooper, E.M., Foster, W.M., Gomes, G.L., Kussin, P.S., MacInnis, J.J., Padhi, B.K., Panigrahi, P., Rodes, C.E., Ryde, I.T., Singha, A.K., Stapleton, H.M., Thornburg, J., Young, C.J., Meyer, J.N. and Pattanayak, S.K., 2017. Biogas stoves reduce firewood use, household air pollution, and hospital visits in Odisha, India. *Environmental Science Technology,* 51: 560–569.

Limpopo DFED. 2004. Limpopo State of the Environment Report (Phase 1). Limpopo Department of Finance and Economic Development. Polokwane.

Lin, F. Fofanah, S.S. Liang, D. 2011. Assessing citizen adoption of e-Government initiatives in Gambia: A validation of the technology acceptance model in information systems success. *Government Information Quarterly,* 28(2): 271-279.

Lupele, J.K., 2002. Action Research case studies of participatory materials development in two community contexts in Zambia. M.Edu Thesis. Rhodes University, Grahamstown.

M'Marete C.K. 2003. Climate and Water Resources in the Limpopo Province. In: Nesamvuni E, Oni S.A, Odhiambo J.J, Nthakheni N. D. (eds). *Agriculture a Corner Stone of the Economy of the Limpopo Province.* Limpopo Department of Agriculture, Polokwane.

Madsen, M. Holm-Nielsen, J.B., and Esbensen, KH, 2011. Monitoring of anaerobic digestion process: A review perspective. *Renewable and Sustainable Energy Reviews,* 15: 3141 – 3155.

Madubansi, M. and Shackleton, C.M. 2006. Changing energy profiles and consumption patterns following electrification in five rural villages, South Africa. *Energy Policy* 34: 4081-4092.

Maillet, E., Mathieu, L. and Sicotte, C. 2015. Modeling factors explaining the acceptance, actual use and satisfaction of nurses using an Electronic Patient Record in acute care settings: An extension of the UTAUT. *International journal of medical informatics*, 84(1): 36-47.

Maingi, J.K. and Marsh, S.E. 2002. Quantifying hydrologic impacts following dam construction along the Tana River, Kenya. *Journal of Arid Environments,* 50: 53–79.

Maluleke, M., Malungani, T., and Steenkamp, K. (Eds.), 2016. Limpopo Environment Outlook Report 2016. Limpopo Provincial Government, Department of Economic Development, Environment and Tourism, South Africa.

Masekoameng, K.E., Simalenga, T.E. and Saidi, T. 2005. Household energy needs and utilization patterns in the Giyani rural communities of Limpopo Province, South Africa. *Journal of Energy in Southern Africa,* 16: 3.

Matsvange, D., Sagonda, R., Kaundikiza, M. and Zaba, P. 2016 Biogas technology diffusion and adoption mechanisms in Zimbabwe. *Africa Insight,* 45(4): 148–166.

Mendis, M.S. and van Nes, W.J. 1999. The Nepal Biogas Support Program: Elements for Success in Rural Household Energy Supply; Ministry of Foreign Affairs: The Hague, Netherlands.

Mendola, M. 2007. Agricultural technology adoption and poverty reduction: A propensity score matching analysis for rural Bangladesh. *Food Policy 32*, *372 – 393.*

Mengistu, M.G., Simane, B., Eshete, G. and Workneh, T.S. 2016. Factors affecting households' decisions in biogas technology adoption, the case of Ofla and Mecha Districts, Northern Ethiopia. *Renew Energy,* 93: 215-227.

Mittal, S., Ahlgren, E. and Shukl, P. 2018. Barriers to biogas dissemination in India: A review. *Energy Policy*, 112: 361–370.

Mshandete, A.M. and Parawira, W. 2009. Biogas technology research in selected sub-Saharan African countries-A review. *African Journal of Biotechnology,* 8: 116-125.

Msibi, S. and Kornelius, G. 2017. Potential for domestic biogas as household energy supply in South Africa. *Journal of Energy in Southern Africa,* 28(2): 1–13.

Mucina, L. and Rutherford, M.C. 2006*. The vegetation of South Africa, Lesotho and Swaziland.* Pretoria: SANBI.

Muk, A. and Chung, C. 2015. Applying the technology acceptance model in a two-country study of SMS advertising. *Journal of Business Research*, 68(1): 1-6.

Mukumba, P., Makaka, G. and Mamphweli, S. 2016. Biogas technology in South Africa, Problems, Challenges and Solutions. *International Journal of Sustainable Energy and Environmental Research,* 5(4): 58-69.

Mutungwazi, A., Mukumba, P. and Makaka, G. 2018. Biogas digester types installed in South Africa: A review. *Renewable and Sustainable Energy Reviews,* 81: 172-180

Muye, H.M. 2015. Energy conversion efficiency of pressurised kerosene and pyramid-shaped clay-lined charcoal cooking stoves. *African Journal of Science, Technology, Innovation and Development,* 7(6), 518-520.

Mwirigi, J., Balana, B., Mugisha, J., Walekhwa, P., Melamu, R., Nakami, S. and Makenzi, P. 2014. Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. *Biomass and Bioenergy,* 70: 17-25.

Mwirigi, J.W., Makenzi, P.M. and Ochola, W.O. 2009. Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts. Kenya. *Energy and Sustainable Development,*13: 106-115.

Myers, N. and Mittermeier, R. A. 2000. Biodiversity hotspots for conservation priorities. *Nature,* 403: 853-854.

National Bank for Agriculture and Rural Development (NABARD). 2007. Biogas. http://www.nabard.org/modelbankprojects/biogas.asp. (Accessed 12 May 2018).

Negro, S.O., Alkemade, F. and Hekkert, M.P. 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews,* 16(6): 3836-46.

Nekhubvi, V. and Tinarwo, D. 2017. Long-term temperature measurement: Biogas digesters fermenting slurry. *Journal of Energy in Southern Africa,* 28(2): 99.106.

Neuman, W.L. 2011. *Social Research Methods*. Boston: Pearson Education.

Nhembo MJ. Assessment of the Adoption Rate of Rainwater Harvesting Technologies for Crop Production in Dodoma, Tanzania: Un-published MA (Rural Dev.) thesis submitted to Sokoine University of Agriculture Morogoro; 2003.

Ni, J.Q. and Nyns, E.J. 1996. New concept for the evaluation of rural biogas management in developing countries. *Energy Conversion and Management,* 37(10): 1525–34.

OECD/IEA, 2016. Statistics South Africa: Balances for 2013. http://www.iea.org/statistics/statisticssearch/report/?year=2013&country=SOUTHAFRIC&product=Balances, (Accessed 18 June 2018).

Oechsner, H., Jungblutt, T., Kranert, M. and Kusch, S. 2012. Editorial: progress in biogas—state of the art and future perspectives. *Engineering in Life Sciences,* 12: 239–40.

Okudoh, V., Trois, C., Workneh, T. and Schmidt, S. 2014. The potential of cassava biomass and applicable technologies for sustainable biogas production in South Africa: A review. *Renewable and Sustainable Energy Reviews,* 39: 1035-52.

Organisation for Economic Cooperation and Development, 2006. *Agricultural Policies in OECD Countries: At a Glance*. Paris: OECD.

Pal, S. 2002. Evaluation study on National Project on Biogas Development (NPBD), renewable energy, domestic biogas. Monitoring and evaluation, New Delhi, India. 1–105.

Parawira, J.K., Mshandete, L.A., Adamas, A. and Sighr, B. 2012. Anaerobic Biogas Generation for Rural Area Energy Provision in Africa. In: D. S. Kumar, ed. *Biogas.* Croatia: In Tech. 35-61.

Parikh, J. 2007. Gender issues in energy policy. *Energy Policy,* 23(9): 745-754

Pathak, H., Jain, N., Bhatia, A., Mohanty, S. and Gupta, N. 2009. Global warming mitigation potential of biogas plants in India. *Environmental Monitoring and Assessment,* 157, 407–418.

Pegels, A. 2010. Renewable energy in South Africa: potentials, barriers and options for support. *Energy Policy,* 38(9): 4945–54.

Pereira, C.P., 2009. *Anaerobic digestion in sustainable biomass chain*. Wgeningen Universiteit (Wageningen University) Wageningen.

Perera, K.K.C.K. and Sugathapala, A.G.T. 2002. Fuelwood – fired cookstoves in Sri Lanka and related issues. *Energy for sustainable development,* 6, 85-94.

Prabhat, P. and Pandey, M. 2015. *Research Methodology: Tools and Techniques.* Romania: Kogaion publishing center.

Prasertsan, S. and Sajjakulnukit, B. 2005. Biomass and biogas energy in Thailand: Potential, opportunity and barriers. *Renewable Energy, 1–12.*

Rajendran, K., Aslanzadeh, S. and Taherzadeh, M.J. 2012. Household biogas digesters: a review. *Energies,* 5: 2911–42.

Raven, R.P.J. M. and Gregersen, K.H., 2007. Biogas plants in Denmark: successes and setbacks. *Renewable and Sustainable Energy Reviews*. 11:116-132.

Reddy, S and Painuly, J.P. 2004. Diffusion of renewable energy technologies: barriers and stakeholders' perspectives. *Renewable Energy,* 29: 1431–47.

Rogers E. 2003. *Diffusion of Innovations.* New York: The Free Press.

Ruffini, A. 2013. SA not using its biogas potential. ESI Africa: Africa's Power Journal. (http://www.esiafrica.com/sa-not-using-its-biogaspotential/)(2016). (Accessed 01 May 2017).

Rwelamira, J. 1999. Effect of socio-economic and gender issues on sustainable resource management, in Kaumbutho, P. and T. Simalenga (Eds), *Conservation Tillage with Animal Traction*. Harare: FAO.

SABIA, Biogas in South Africa German Conference. 2015; Sandton, South Africa.

SABIA. Biogas in South Africa Conference: Sandton, South Africa; 2013.

SAIREC South Africa International Renewable Energy Conference. 2015; Cape Town, 4-7 October.

Salomon, K.R. and Lora, E.S. 2009. Estimate of the electric energy generating potential for different sources of biogas in Brazil. *Biomass Bioenergy,* 3(9): 1101-1107.

Sang, S., Lee J.D. and Lee J. 2009. E-government adoption in ASEAN: the case of Cambodia. *Internet Research,* 19(5): 517-534.

Sardianou, E. and Genoudi, P. 2013. Which factors affect the willingness of consumers to adopt renewable energies? *Renewable Energy,* 57: 1–4.

Scarlat, N. 2015. Evaluation of energy potential of Municipal Solid Waste from African Cities. *Renewable and Sustainable Energy Reviews,* 50: 1269-1296.

Senkondo, E.M.M., Lazaro, E.A. and Kajiru G.J. 1999. Factors affecting the adoption of Rain water harvesting Technologies in Western Pare Lowlands of Tanzania**.** *Tanzania Journal of Agricultural Sciences,* 1(1): 81-89.

Sila, I. 2015. The state of empirical research on the adoption and diffusion of business-to-business e-commerce. *International Journal of Electronic Business.* 12(3): 258-301.

Singh K.J. and Sooch, S.S. 2004. Comparative study of economics of different models of family size biogas plants for state of Punjab, India. *Energy Conversion and Management* 45: 1329-1341.

Singh, K. 2007. *Quantitative Social Research Methods.* Los Angeles: Sage Publications.

Sinja, J., Karugia, J., Baltenweck, I., Waithaka, M., Miano M.D., Nyikal R., and Romney, D. 2004. *Farmer Perception of Technology and its Impact on Technology Uptake: The Case of Fodder Legume in Central Kenya Highlands*. African Association of Agricultural Economists. Proceedings of the Inaugural Symposium, 6-8, December 2004, Grand Regency Hotel, Nairobi, Kenya. http://ageconsearch.umn.edu/bitstream/ (Accessed 02 July 2016).

Smith, J.U. 2011. The Potential of Small-Scale Biogas Digesters to Alleviate Poverty and Improve Long Term Sustainability of Ecosystem Services in Sub-Saharan Africa, Interdisciplinary Expert Workshop, Kampala (Group I) and Addis Ababa (Group II), 4-5.

Smith, K., Mehta, S. and Maeusezahl-Feuz, M. 2004, Indoor Air Pollution from Household Use of Solid Fuels, in Ezzati, M., Rogers, A., Lopez, A., Murray C. (Eds), *Comparative Quantification of Health Risks*, Volume 2. Geneva: WHO.

Somda, J., Nianogo J., Nassa S. and Sanou S. 2002. Soil fertility management and socioeconomic factors in crop-livestock systems in Burkina Faso: a case study of composting technology. *Ecological Economics,* 43: 175-183.

South Africa Channel, 2010. www.southafrica.com/limpopo/climate/ (accessed 19 April 2016).

Spuchľáková, E. and Cúg, J. 2014. Lost Given Default and the Credit risk. *International Conference on Management, Education and Business Information Science*, 12-15.

Stake, R. 1995. *The Art of case study Research*. London: Sage.

Statistics South Africa 2001.*Census: Concepts and Definitions*. Report no. 03-02-26.

Statistics South Africa 2011.*Census: Concepts and Definitions*. Report no. 03-02-26.

Statistics South Africa. 2013b. In-depth analysis of the general household survey data. GHS Series, volume V, Energy, 2002-2012. Pretoria, South Africa.

Statistics South Africa. Census: Concepts and Definitions. Report no. 03-02-26; 2011.

Stern, N. 2006.*The Economics of Climate Change*. London: HM Treasury.

Steyn, M. and Minitt, R.C.A. 2010. Thermal coal products in South Africa. *Journal of the Southern Africa Institute of Mining and Metallurgy,* 110: 593–9.

Subedi, B.P., Pandey, S.S., Pandey, A., Rana, E.B., Bhattarai, S., Banskota, T.R., Charmakar, S. and Tamrakar, R. 2014. Guidelines for measuring carbon stocks in community-managed forests. ANSAB, FECOFUN, ICIMOD, NORAD. http://www. ansab.org/wp-content/uploads/2010/08/Carbon-Measurement-Guideline-REDD-final.pdf (accessed 25 June 2018).

Surendra, K.C., Takara, D., Hashimoto, A.G. and Khanal, S.K. 2014. Biogas as a sustainable energy source for developing countries: Opportunities and challenges. *Renewable and Sustainable Energy Reviews,* 31: 846-859.

Suri, H. 2011. Purposeful Sampling in Qualitative Research Synthesis. *Qualitative Research Journal,* 11(2): 63-75.

Taherdoost, H.A. 2018. Review of technology acceptance and adoption models and theories. *Procedia manufacturing,* 22: 960-967.

Tiepelt, M. 2015. Status quo of the biogas sector development in South Africa as well as the way forward. GIZ SAGEN Short-term Biogas Training Seminar: Pretoria, South Africa.

Tomar, S.S. 1995. Status of biogas plants in India—an overview. *Energy for Sustainable Development,* 1(5): 53–6.

UNDP, 2013. *The energy access situation in developing countries: A review focusing on the least developed countries and Sub Saharan Africa,* New York: UNDP.

UNDP. United Nations Environment Programme 2011. Emerging issues in our global environment. UNEP. Nairobi, Kenya.

UNDP. United Nations Environment Programme 2013. Emerging issues in our global environment. UNEP. Nairobi, Kenya; 2013.

UNEP. 2012. Financing renewable energy in developing countries: Drivers and barriers for private finance in sub-Saharan Africa. New York: UNEP Finance Initiative.

Venkataraman, C., Sagar, A.D., Habib, G., Lam, N. and Smith, K.R. 2010. The Indian National Initiative for advanced biomass cookstoves: The benefits of clean combustion. *Energy for Sustainable Development*, 14: 63–72.

Venkatesh, V. 2003. User acceptance of information technology: Towards a unified view. *MIS Quarterly,* 27(3): 425-478.

Venkatesh, V., Morris, M., Davis, G., and Davis, F. 2003. User acceptance of information technology: Toward a unified view. *MIS Quarterly, 27,* 425-478.

Victor, D. 2005. *The Effects of Power Sector Reform on Energy Services for the Poor*. New York: United Nations.

Walekhwa, P.N., Mugisha, J. and Drake L. 2009. Biogas energy from family-sized digesters in Uganda: critical factors and policy implications. *Energy Policy,* 37: 2754-2762.

Walwyn, D. and Brent, A. 2015. Renewable energy gathers steam in South Africa. *Renewable and Sustainable Energy Reviews,* 41: 390-401.

Wang, J. 2014. Decentralized biogas technology of anaerobic digestion and farm ecosystem: opportunities and challenges. *Frontiers of Energy Research,* 2(10): 1-12.

Watson, R.T., Ho, T.H. and Raman, K.S. 1994. Culture: A fourth dimension of group support systems. Communications of the ACM 37(10): pp. 55.

Weerakkody, V., El-Haddadeh, R., Al-Sobhi, F., Shareef, M.M. and Dwivedi, Y.K. 2013. Examining the influence of intermediaries in facilitating e-government adoption: An empirical investigation. *International Journal of Information Management,* 33: 716-725.

Werner, U., Stohr, U., and Hees, N. 1989. *Biogas Plants in Animal Husbandry*. Braunschweig: Friedr Vieweg and Sohn.

Winkler, B., Lemke, S, Ritter, J. and Lewandowski, I. 2017. Integrated assessment of renewable energy potential: Approach and application in rural South Africa. *Environmental Innovation and Societal Transitions,* 24: 17–31.

Winrock International, 2007. Africa biogas initiative: potential for growth and models for commercialization. Arkansas, USA: Winrock International.

World Bank, 1998. Greenhouse Gas Assessment Handbook: a Practical Guidance Document for the Assessment of Project-level Greenhouse Gas Emissions. Global Environment Division, the World Bank, USA.

World Bank, 2006. Greenhouse Gas Assessment Handbook: a Practical Guidance Document for the Assessment of Project-level Greenhouse Gas Emissions. Global Environment Division. USA: the World Bank.

World Bank, 2016. The Little Green Data Book, International Bank for Reconstruction and Development. Washington DC: World Bank.

World Energy Council, 2003. The Challenges of Rural Energy Poverty in Developing Countries www.worldenergy.org (Accessed 18 November 2017).

World Health Organization, 2006. *Fuel for Life*. Geneva: WHO.

Yadvika, S., Sreekrishnan, T.R., Kohli, S. and Rana, V. 2004. Enhancement of biogas production from solid substrates using different techniques – A review. Bioresource technology 95(1): 1-10.

Yin, H. and Li, C. 2001. Human impacts on floods and flood disasters on the Yangtze River. *Geomorphology,* 41: 105-109.

Yin, R.K. 2011. *Qualitative research from start to finish.* New York, NY, US: The Guilford Press.

Appendix 1.

Household Survey (Questionnaire)

Greetings!

My name is Uhunamure Solomon, a postgraduate student from the University of Venda, Thohoyandou. I am conducting a research study regarding adoption and utilisation of biogas technology in Limpopo Province. Your household have been selected randomly from other households in the area.

The aim of this questionnaire is for no other reason than academic purposes. Participation is voluntary and respondents can withdraw at any time. Respondents will not be exposed to any form of harm either physically or psychologically. Privacy and identity of the respondents will be safeguarded. This implies that the information will be kept confidential.

NB: Please, Provide answers and cross(x) in the appropriate box next to the question.

For further questions about the survey you can ask me or my promoters: Dr NS Nethengwe; Tel: 015 962 8593, email or Dr D Tinarwo; Tel: 015 962 8918 or email (Office Hours).

Name of Village [ ] **Questionnaire ID** [ ]

Date	
Interviewer	
Translator	
Respondent agreed to be interviewed	Yes No
Signature of interviewer	
Town/Area	
GPS Co-ordinates	

SECTION A: Demographic and socio-economic characteristics information

1. Gender

Male	1	
Female	2	

2. Age in Years

Less than 20	1	
21-30	2	
31-40	3	
41-50	4	
51 and above	5	

3. Marital status

Single	1	
Married	2	
Divorced	3	
Widowed	4	
Others	5	

4. Are you the head of house?

Yes	1	
No	2	

5. What is your highest level of education?

No formal education	1	
Primary	2	
Secondary	3	
Tertiary	4	

6. What are your occupation details?

Employed	1	

Self employed	2	
Unemployed	3	

7. What is your monthly income?

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

8. What is the number of your dependants?

1	1	
2	2	
3	3	
4	4	
Above 4	5	

9. Livestock ownership

Indicate number and management system of the various livestock you own.

Type	**Number of animals**	**Management**	**Key to management System**
Cattle			
Goats			1 = Zero grazing 2 = Semi grazing 3 = Open grazing
Sheep			
Pigs			
Donkeys			
Chicken/ducks			

Others (specify)			

10. Crop production

Are you involved in crop production?

Yes	1	
No	2	

11. If yes, list the crops you grow……………………………………………………………

12. Do you apply fertilizer to your crops?

Yes	1	
No	2	

SECTION B: Resources Availability

13. Are the following resources available in your area?

		1	2
i	Water for domestic use		
ii	Fuelwood for cooking		

14. Availability of the water resources

Readily available	1	
In short supply	2	

15. Availability of the fuelwood resources

Readily available	1	
In short supply	2	
Not available	3	

16. Distance to domestic water resource

<100m	1	
100-500m	2	

501-1Km	3	
Above 1Km	4	

17. Source of water

River/Stream	1	
Municipal tap inside the house	2	
Municipal tap outside the house	3	
Borehole	4	
Rainwater tank	5	
Community stand/Municipal tap	6	
Others (specify)	7	

18. Distance to domestic fuelwood resource

<100m	1	
100-500m	2	
501-1Km	3	
Above 1Km	4	

19. From most to least, what is the major source of fuel for domestic uses?

Electricity	1	
Fuelwood	2	
Charcoal	3	
Solar energy	4	
Biogas	5	
Others (Specify)	6	

20. If the source is fuelwood, indicate where you obtain the fuelwood from?

Public Forest reserve	1	
Planted trees	2	
Virgin land	3	
Trees left in the farmland	4	
Private forest reserve	5	
Fallow areas	6	
Neighbour's village land	7	
Sellers/vendors	8	

21. Monthly estimated amount of fuelwood used in Kilograms

10-15kg	1	
15-20kg	2	
20-25kg	3	
25-30kg	4	
30-35kg	5	
35-40kg	6	
40kg and above	7	

22. How would you rank the problem of fuelwood shortage in your area?

Serious	1	
Moderate	2	
Small	3	

23. What do you think is the best strategy toward solving the problem of fuelwood?

Migrate to an area closer to the source of fuelwood	1	
Plant trees	2	
Stop charcoal making	3	

Prevent bush fires	4	
Looking for alternative sources of energy	5	
Others (specify)	6	

24. Do you know any alternative energy source other than fuelwood?

Yes	1	
No	2	

25. If yes, mention them

(i) ……………………………………….……………………………..

(ii) ………………………….……………..…………………………….

(iii) ……………………………………………………………………..

26. For the alternative energy sources you mentioned above, which ones do you use?

(i) ……………………………………….……………………………..

(ii) ………………………….……………..…………………………….

(iii) ……………………………………………………………………..

27. Who is responsible for energy availability in your household?

Wife	1	
Husband	2	
Wife and children	3	
Husband and children	4	
Children only	5	
Everybody	6	

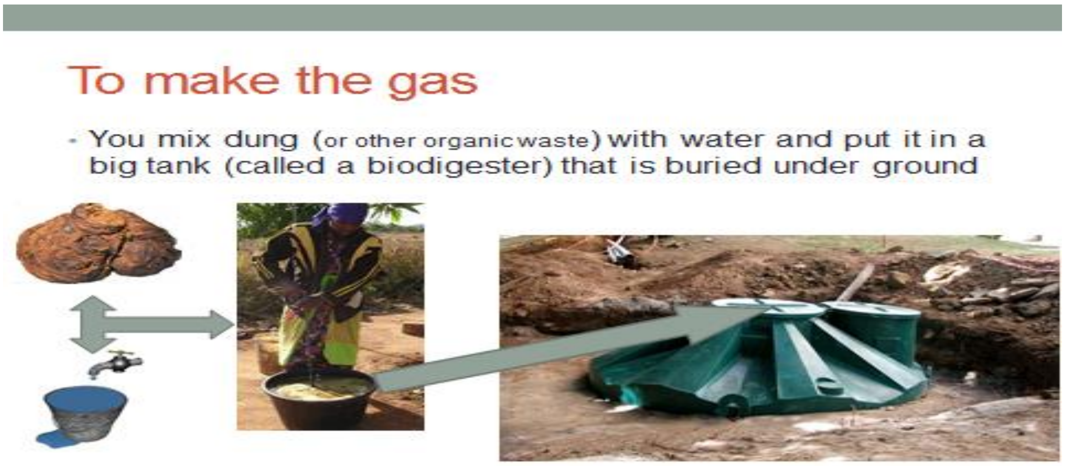
SECTION C: Awareness and Perceptions of Biogas Technology

Biodigester Explanation for Household

Biogas can be produced from any organic waste, like dung (from all kinds of animals), human waste, and kitchen waste (remainders of vegetables).

To generate the gas, a biodigester is used. A biodigester is a big container that is buried in the ground (**show pictures*).

The waste is mixed with water and enters the digester where bacteria generate the gas (**can be analogised to compost getting hot*).



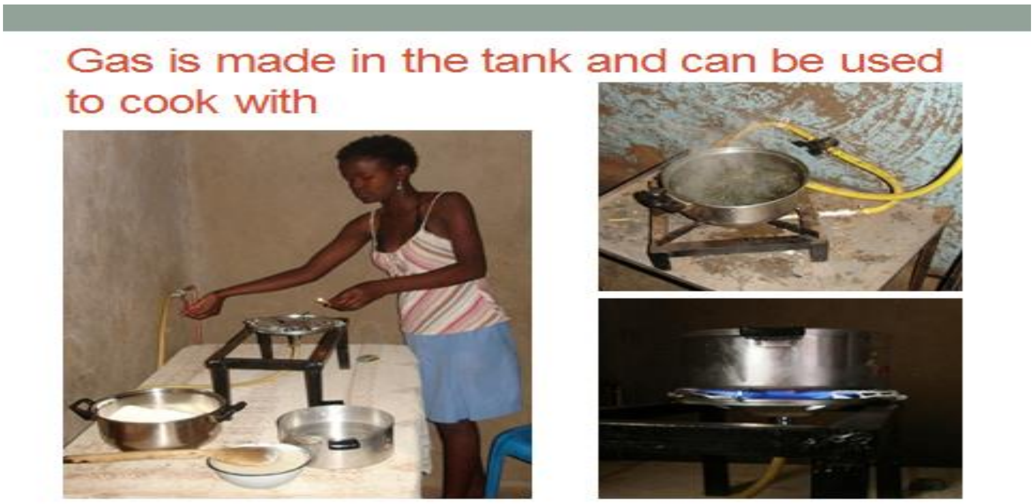
The gas is piped from the top of the digester and can be used for cooking (**show pictures*).

At the one side of the digester the waste goes into the digester, and at the other side the residue (bioslurry) comes out. This bio-slurry can be used as a fertiliser to grow food for yourself and your animals. Many people around the world and in Africa are already using biogas for cooking and the bioslurry for fertiliser.

Requirements to run a biodigester:

If you have a biogas digester at your home, you will have to **fill the digester each day** with 20kg of dung (**show bucket*), and/or other organic waste, and 20L of water (**show bucket*).

The dung might be collected from a kraal where the cattle (or any other livestock) sleep at night. **If you have access to this gas, you will not have to use any other sources of energy for your cooking needs**. If you have sufficient animal dung and install a **biogas digester, then you will not have to search for fuelwood, buy paraffin or gas for cooking**.



ADVANTAGES OF BIOGAS

- It will give you energy for cooking.
- Biogas will save you time that you spend collecting fuelwood. This time can be used for any other activity, such as agriculture and/or leisure.
- When you cook on biogas, you help to protect the environment because you will cut fewer trees for wood.
- Cooking with biogas is also good for your health because you do not have to inhale the smoke if you cooked on an open fire.
- You will get fertiliser, for free.

Building the digester may create a small number of jobs.

28. Have you ever heard about the biogas technology?

Yes	1	
No	2	

29 (i) If yes, could briefly explain…………………………………………….

30. Have you adopted the technology?

Yes	1	
No	2	

31 (i) If not, why?..

…………………………………………………………………….

32. Who gave you information about biogas technology?

Government Organisation	1	
NGO	2	
Biogas Researchers	3	
Friends, Relatives, Neighbours	4	
Others (specify)	5	

33. If you have not adopted biogas technology give the main reasons?

No technological benefits	1	
High cost of the technology	2	
Shortage of house labour	3	
Availability of fuelwood	4	
Not aware of the technology	5	
Inappropriate for household	6	
Others (specify)	7	

34. What is your comment concerning biogas technology as alternative energy source?

Appropriate technology	1	
Inappropriate technology	2	

35. What is your recommendation on biogas technology promotion?

Strongly recommended	1	
Moderately recommended	2	
Not recommended	3	

36. Circle one number based on whether you strongly agree (SA), Agree (A), undecided (UD), Disagree (DA) or strongly disagree (SD) to the statement.

Statement	**SA**	**A**	**UD**	**DA**	**SD**
Biogas can help solve the problem of fuelwood for cooking.	5	4	3	2	1
Biogas technology can help to improve soil fertility.	5	4	3	2	1
Biogas technology can improve hygiene due to the use of wastes.	5	4	3	2	1
Biogas technology can reduce the rate of deforestation.	5	4	3	2	1
Biogas can relieve women workload and save time used for fuelwood collections.	5	4	3	2	1
Generally benefits of Biogas technology over weighs limitation/weakness.	5	4	3	2	1
Government and other stakeholders have not sufficiently promoted biogas technology.	5	4	3	2	1

SECTION D: Biogas Technology Experience. For Biogas Users Only

37. (A). Do you burn wood in stove?

Yes	1	
No	2	

38. (B). What type of stove do you use?

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

39. Monthly estimated amount of fuelwood used in Kilograms before biogas installation?

10-15kg	1	
15-20kg	2	
20-25kg	3	
25-30kg	4	

30-35kg	5	
35-40kg	6	
40kg and above	7	

40. Monthly estimated amount of fuelwood used in Kilograms after biogas installation?

10-15kg	1	
15-20kg	2	
20-25kg	3	
25-30kg	4	
30-35kg	5	
35-40kg	6	
40kg and above	7	

41. When did you start using biogas technology as source of energy (year) ……….

42. Who/ which company built you a biogas plant (Name) ……………...…………

43. Where did you get money for biogas Installation and maintenance?

Own savings	1	
Loan/Credit	2	
Sponsored by Biogas project	3	
Own contribution and subsidy from Biogas project	4	
Own contribution and subsidy from the Government	5	
Others (specify)	6	

44. What influenced your decision in adopting Biogas technology?

Out of my own interest	1	
Acute problem of fuelwood for domestic use	2	
Acute problem of fuelwood for domestic use	3	

Influenced by friends/neighbours who have already adopted Biogas technology	4	
Awareness of environmental problems	5	
Bye- laws against tree cutting	6	
High costs of other energy sources	7	
Sensitized by the media	8	
Given/promised some incentives (Specify)	9	
Others (specify)	10	

45. Is your biogas plant functional?

Yes	1	
No	2	

46. If yes, what are the benefits of using the technology?

Easy and fast in use	1	
Clean, no soot produced as compared to fuelwood	2	
Low running cost after installation costs	3	
Saving time used for fuelwood collection	4	
Others (specify)	5	

47. If your biogas plant is not functioning, for how long now?

Days	1	
Weeks	2	
Months	3	
Years	4	

48. What are the reasons for none functioning of your biogas plant?

Technical problems	1	
Availability of dung	2	
I don’t know	3	
Others (specify)	4	

49. How frequent do Biogas installers visit you to see the performance of the plant?

Often	1	
Not often	2	
Never came back after installation	3	

50. Are technical services available when needed?

Easily available	1	
Available but not frequent	2	
Not available	3	

51. Is your household labour able to accomplish the activities required to run a biogas Related activities?

Yes	1	
No	2	

52. If no, what do you do to solve the problem of shortage of labour?

Use hired labour (Fulltime)	1	
Use hired labour (part time)	2	
Use of own off-work hours	3	
Others (specify)	4	

53. What are the weaknesses/ limitations of biogas technology?

High costs of installation	1	
Difficult to operate	2	
Unavailability of feed stocks	3	
High maintenance costs	4	
Difficult in getting maintenance services	5	
Not producing enough energy for cooking	6	
Others (specify)	7	

54. On the scale of 1 – 5, (1 = Poorest score, 5 = Best score) compare and score the biogas stove as a cooking device against other cooking devices in terms of the following set criteria:

Criteria	**Fuelwood Stove**					**Charcoal stove**					**Paraffin Stove**					**LPG stove**					**Electric Stove**				
Technical Evaluation																									
Fuel consumed	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cooking time	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Durability	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Reliability	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Sophistication	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Size/Space/ weight needs	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Ruggedness	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Seasonal/continuous use	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Nutritional level of food cooked	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Economic Evaluation																									
Initial cost	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Fuel cost	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Maintenance cost	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Interest rate on loan for device	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Subsidy availability	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Environmental Evaluation																									
Air pollution levels	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Deforestation potential	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Eutrophication potential	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Soil degradation levels	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Criteria	**FuelWood Stove**					**Charcoal Stove**					**Paraffin Stove**					**LPG Stove**					**Electric Stove**				
Heavy metal pollution	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Commercial Evaluation																									
Improvement in models	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Availability of spares and aftersales service	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Distribution network	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Market research needs	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Need for training	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Social Evaluation																									
Human drudgery	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Overall safety in use	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Employment generation potential	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Gender sensitivity	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Behavioural Evaluation																									
Aesthetics	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Motivation to buy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Taste of food prepared	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cleanliness of utensils	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Ease of operation	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Exclusivity of types of dishes to be cooked on	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Need for extra cooking device/stove	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

SECTION E: Promotion of Biogas Technology

55. Are there any campaigns, seminars for promotion of biogas technology in your area?

Yes	1	
No	2	

56. If Yes how many time were the campaigns/seminars in last year……………

57. Have you ever attended any of the following?

Training workshop on biogas technology	1	
Biogas village campaign	2	
Public/Political biogas campaign	3	
Visited Biogas project for consultation	4	

58. Which promotion ways/strategies are being used for Biogas dissemination?

(i) ……………………………………….…………………………….

(ii) ……………………….……………..……………………………

(iii) ……………………………………………………………………..

59. What are the weaknesses of the strategies mentioned above has?

(i) ……………………………………….…………………………….

(ii) ……………………….……………..……………………………

(iii) ……………………………………………………………………..

60. In your opinion, is the South African Government fully involved in promoting biogas technology?

Yes	1	
No	2	

61. The following are the factors assumed to promote adoption of biogas technology. Indicate the level of peoples' access to the factors in your area.

Level of access

No or negligible access	1	
Low level of access	2	
Access is satisfactory	3	
Access is relatively high	4	

62. Factor assumed to influence adoption of biogas technology

	Level of access **On the scale of 1 – 5, (1 = Poorest score, 5 = Best score**				
Strong demand from people for a solution to energy crisis problem					
Awareness and knowledge of the technology					
Access to credits and other sources of funds for affordability					
Subsidies and other assistance to people					
Support and encouragement from municipal council officials					
Availability of technical assistance and experienced extension officers					
Rewarding of good performers					
Use of good performers as models and to train others					
Use of village leaders in promotion of the technology					
Advertisement and promotion activities					

Appendix 2.

Interview Guide for Organisations Dealing with Biogas Technology

1. Name of Organisation ………………………………………….……………….

2. When did the organisation started disseminating biogas technology in the Limpopo Province?................................(Months/Years)

3. Are there other organisation in the province dealing on biogas technology? If yes, mention them……………………………………..

4. What motivated your organisation in engaging into biogas technology?

5. What were the projects main objectives and at what level are the objectives?

6. What were the target group of people to be reached by biogas technology as per the organisations plan?

7. Has the target been met? If not, what are the reason?

8. How many villages in the Limpopo province have you reached with the technology?

9. Do you think people are aware of biogas technology in the province?

10. How many households in the province have adopted the technology?

11. Number of biogas installed per year in the province

Year	**Number of Plants installed**	**Targeted number**	**Reason for variance (if any)**	**Districts covered**

12. What is the percentage of adopters as per population of the area? ……………

13. If the adopters' percentage is small compared to the expected, what do you think are the factors influencing the adoption of the technology?

14. What percentage of biogas plants installed are functional?

…………………………………………….…………………………………………………
…………………………………………………………………

15. How much does the biogas plant (family size) cost (a) in year 200 …………

(b) 2016

16. Apart from animal dung what other materials can be used as feed-stocks for

Biogas plants? (i) …………… (ii) ……………….. (iii)…………………….

17. What are the major complains received from users of the technology?

18. What are the technical problems affecting the functionality of biogas plants?

19. What have you done or you suggest as remedy to the problems mentioned in your response to 17 and 18 above?

20. Did your organisation give any support/ contribution to people who adopted or who intend to adopt biogas technology? ……………………………..……….

21. If yes what kind of support and at what level?

Kind of support	Level of contribution (%)
(i) ………………………………………	…….…………………………
(ii)………………………………………	……………….……………
(iii)………………………………………	……………………………

22. Are the technical assistance/services available when needed by biogas adopters?

23. How frequent do your technicians visit people who adopted the technology?

24. What are the strategies your organisation using to disseminate biogas technology?

25. What are the problems facing your organisation in disseminating the technology?

26. What is your opinion on Governments' involvement in biogas technology?

Dissemination? ....

27. What support does your organisation receive from the Government in the technology dissemination efforts?

29. As organisation, what are your suggestion to the Government on:

(i) Promotion of technology ……….…………………………………………

(ii) Affordability of the technology …..…………………………………….

(iii) Sustainability of the technology ………………………………………

(iv) Plant types and sizes …………………………………………………

28. Can you summarize the roles supposed to be played by the following Institutions/ organisations /individuals in Promotion of biogas technology?

Institution/organisation/ Individuals	**Role to be played in dissemination of biogas technology**
Department responsible	

Non-Governmental Organisations	
District’s Natural resources Department	
Village Government	
Citizens	
Politicians	
Researchers and Professionals	

29. Any comment on sustainability of your project as far as Biogas dissemination is concerned? ………………………………………………………………

30. From your experience in which setting does Biogas technology is more appropriate?

(i) Rural,

(ii) Sub-urban,

(iii) Urban

(iv) Both

Appendix 3.

Check list to the Government Departments/Institutions Dealing with Biogas Technology

1. Policy statements and strategies on alternative energy sources versus its Implementation status
2. Data on energy situation and specifically Rural energy in Limpopo province
3. Renewable energy technologies so far implemented in Limpopo province
4. Please if you can provide data on the following;
   - Government organisations dealing with biogas dissemination (Years established, location over the country
   - Non-Governmental organisations dealing with biogas technology, Biogas plants so far installed by regions and years of installation

5. Who monitors the operations of NGOs dealing with energy issues and what are the reporting mechanisms or channels used by both projects owners and the public (beneficiaries of the technology).

6. What are the promotion strategies and support services offered by the ministry/government organisations to Biogas projects and the community to facilitate promotion of biogas technology?

7. What are the challenges facing the Ministry/department/organisation on promotion of renewable energy technologies particularly Biogas technology.

Appendix 4.

Check list for Focus Group Discussion

1. What are your comments on deforestation status in your area and what are the major causes?

………………………………………………………………………………………..

……………………………………………………..………………………………

2. Are there energy problem in your area? If yes to what extent

………………………………………………………………………………………..

……………………………………………………..………………………………

3. Do you see a need for alternative energy sources? If yes which alternatives do you think are appropriate to your area? Think of environment, costs, availability of raw materials, technical services and technological know-how and cultural acceptance to the surrounding community.

……………………………………………………………….……………………

……………………………………………………………….……………………

4. What is acceptance status of biogas technology in your area, do you think the technology has been adopted to the expected level?

………………………………………………………………………………………

………………………………………………………………………...…………

5. If you think adoption is low what are causes?

………………………………………………………………………………………..

……………………………………………………..………………………………

6. For biogas users; what were you expectation from biogas technology. Are the expectations met?

………………………………………………………………………………………..

……………………………………………………..………………………………

7. How did Biogas technology reached this area, what were the dissemination strategies used by disseminators?

………………………………………………………………………………………..

……………………………………………………..………………………………

8. The following are biogas stakeholders; rank them according to how you perceive their participation level in promotion of biogas technology as alternative energy source.

SN	Stakeholder	Perceived participation level
1.	Department of Energy and Minerals	
2.	Extension officers at District level	
3.	Village Government	
4.	Political leaders e.g. Members of Parliament	
5.	Researchers and other professionals	
6.	Non-Governmental Organisations dealing with BT	
7.	Respective community (Biogas adopters and Potential adopters)	

9. For biogas adopters; do you have enough knowledge about biogas to the extent of being able to share the information with others? If not what areas do you think need more education/training?

………………………………………………………………………………………..

…………………………………………………..……………………………….

10. The survey on biogas in this area has shown that most of installed biogas plants are not functioning,

10.1. What are the major causes?

10.2 Suggest their remedies.