Success and failure of biogas technology systems in rural Kenya: An analysis of the factors influencing uptake and the success rate in Kiambu and Embu counties

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Declaration

I, Stephen Ngugi Wamwea, declare that this Master thesis is a result of my research, investigations and findings. Sources of information other than my own have been acknowledged and a reference list has been appended. This work has not been previously submitted to any other university for award of any type of academic degree.

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SIGNED..

Oslo, December 5th 2017

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Abstract

Since biogas technology was introduced in Kenya in 1954, adoption and sustainability of the technology is still low, currently at 0.03% of the 1.2 million households with the technical potential to own biogas, especially in the rural areas. This low success rate is as a result of organizational, institutional, technical, cultural and socio-economic factors. Similarly, widespread adoption of the biogas technology has been hampered by lack of information on its benefits and the high costs of the initial designs and systems. Other constraints that hinder the adoption and sustainability of the technology by the rural farmers are lack of technical knowledge on maintenance and operation, wrong feeding regimes of the digesters and incorrect ratio of feedstock mixture. The farmers also lack capital and credit facilities, subsidy provision, and government extension services. Kenya currently suffers from the intertwined problems of climate change, food insecurity and energy poverty. Biogas technology has been regarded as a solution to these three problems. Although biogas technology has been thouroghly studied in Europe and Asia, little effort has been made to study the same in sub-Saharan Africa. Biogas technology success has continued to be problematic in spite of the partnerships with international organisations such as SNV and GTZ and being linked to poverty alleviation and development in rural areas

The purpose of this research is to investigate the success and failure of biogas systems by analysing the factors that influence the adoption, uptake, sustainability and the success rate of biogas technology in Kiambu and Embu counties of Kenya. The study sought to gather information on the physical conditions of biogas digesters, how the biogas technology functions, the feelings and perceptions of the people who have installed the technology, the impact that biogas has on users and whether the rural farmers have the necessary capacity to adopt and maintain the biogas technology. This study was futher to identify under which technical, social, economic, and cultural conditions the biogas technology can work best and ensure long-time functioning. In order to achieve these objectives, the study carried out a detailed analysis of biogas digester systems that have been installed for more than five years. Recent designs are found to perform better than the older ones. This research analysed the entire biogas system, factors affecting its productivity as well as its stability. It was also necessary to study the faults in in the biogas systems which are found in five main subsystems namely structural components, biogas utilization equipments, piping system, biogas production and effluent disposal system. The outcome of this study shall identify under which

conditions biogas technology can work best and sustainably, that is, the success and failure of the systems.

The sample size was 176 respondents. Both qualitative and quantitative research methods were used in the study based on the problem analysis method in order to find out the problems associated with the failure and success of biogas technology systems. The activities of this study were divided into four phases namely desk study, data collection, data analysis and thesis writing phase. The secondary data was collected from scholary sources and are referenced in this thesis. The limitations were that the sample size of 176 respondents was too small quantitatively. In addition, sensitive personal information gathered during interviews from the respondents could not be guaranteed to be 100% trustworthy. Finally, time and finances to conduct this study thoroughly was also a limitation.

This study found that the common biogas digesters sizes were 4,6,8,10,12 m^3. Cow dung was the most regular feedstock used. Most respondents did not follow the recommended measurements including the mixture ratio of dung and water of 1:1, the substrate temperature which is best between 32-40°C and the substrate pH which is best between 6.5-7.5. However, almost all respondents removed the condensed water from the gas pipeline using a water trap. Similarly, most respondents did not know why the flame colour was either yellow or blue and what that indicated. A yellow flame is an indicator that the biogas produced is not enough while a blue flame indicates the biogas produced is enough. Those who had adopted the biogas technology were not necessarily of the medium or high educational levels as has been previously found. Neither was adoption determined by the number of livestock or the size of land ownership. Slurry was used as an alternative to chemical fertilizer and also increased algae growth in fish ponds which the fish feed on, thus increasing fish production. Satisfaction from using biogas was derived from the benefits gained including time and money saved, reduced workload, improved health and quality of life. Women were the main beneficiaries within a family setup. Payback period of the biogas technology was found to be 1.7 years. The Net Present Value (NPV) was positive making the technology worth investing in. The economic benefits to the wider society from adopting the biogas technology were found to be cleaner environment, conservation of forest, increased food production, reduced carbon emissions/global warming, improved health, economic growth, poverty alleviation, increased employment opportunities, more free time for women, increased happiness due to better lifestyle and food security. A modern fibreglass biogas digester was found to be more

convenient than the traditional digesters in terms of cost, strength, transportation, installation, repair and maintenance. Key actors in the biogas industry which are the government, private sector and NGOs should work together to enhance the quality and the quantity of biogas technology in Kenya. In addition, further research is necessary on the improvement on how biogas systems can work best.

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Key words: *Biogas system, digester, anaerobic digestion, anaerobic bacteria, substrate, slurry, methane.*

TABLE OF CONTENTS

APPEDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS.

LIST OF SYMBOLS AND ACRONYMS

GoK	Government of Kenya
GTZ	German Agency for Technical Cooperation
KARI	Kenya Agricultural Research Institute
KNBS	Kenya National Bureau of Statistics
SNV	SNV Netherlands Development Organisation
NIBIO	Norwegian Institute of Bio-economy Research
LPG	Liquid Petroleum Gas
N-P-K	Ratio of Elements in Chemical Fertilizer where N means Nitrogen, P means Phosphorus and K means Potassium
N_{pr}	Biogas Annual Operating Cost
°C	Degrees Celcius
θ	Hydraulic Retentione Time (HRT)
%	Percent
D	Biogas Payback Time in Years
I	Biogas Installation Cost
P_r	Annual Benefit from Biogas
kg	Kilograms
kW	Kilowatt
NPV	Net Present Value
CH_4	Methane
CO_2	Carbon Dioxide
H_2S	Hydrogen Sulphide
pH	A Measure of the Acidity or Alkalinity of a Solution.
KSh	Kenya Shillings
US$	United States Dollar

CHAPTER 1

INTRODUCTION

Over 77% out of the 40 million Kenyans live in the rural areas and depend on subsistence rain-fed agriculture as their main source of livelihood. Research shows that 29% of the total Gross National Product of Kenya is agriculture-based economy (Day, Chen, Anderson, & Steinberg, 1990). Agriculture supports the livelihoods of 80% of the rural population although only 22% of land is arable in Kenya (Omiti, Otieno, Nyanamba, & McCullough, 2009).

The rural population is characterized by low levels of per-capita income and high population growth. Kenya, just like other developing countries, is faced with acute energy challenges. Most people in the rural areas depend on biomass in the form of firewood and charcoal as their source of cooking, lighting and heating energy (Murphy, 2001). In rural Kenya, firewood, charcoal and kerosene are mainly used for cooking, lighting and heating (Justas K Laichena, 1989).

A survey carried out by the Kenya Forest Service estimated that the Kenya forest cover is a meagre 1.5% as a result of deforestation, mainly for firewood and charcoal (Sovacool, Kryman, & Smith, 2015). Other causes of deforestation are agricultural expansion, overgrazing, mining, and fuel collection (Rowse, 2011). The forested area in Kenya is low in comparison to 9% and 21% for Africa and the world respectively, which is far less than the recommended minimum of 10% per country by the United Nations Environmental Programme (UNEP) (NGIGI & Tateishi, 2004).

In Kenya, the three main sources of energy are biomass, petroleum, and electricity, with a consumption share of 74.6%, 19.1% and 5.9% respectively, although only 4% are connected to electricity in the rural areas (Kiplagat, Wang, & Li, 2011). Scarcity of biomass as a source of energy in Kenya has resulted in energy poverty especially in the rural areas. This has justified the demand to exploit alternative sources of renewable and sustainable energy such as biogas, solar, wind, hydro and geothermal energy. According to Kiplagat et al. (2011), Kenya is rich in renewable energy resources, including hydropower, geothermal, biogas, solar and wind. Biogas technology has been identified as the most appropriate alternative in the Kenyan rural areas due to the availability of the feedstock needed (Nzila et al., 2012). In fact all biomass can be degraded to biogas (Rajendran, Aslanzadeh, & Taherzadeh, 2012).

Because it is simple to generate, convenient and cheap renewable energy, biogas is the most promising energy source for rural households (Karanja & Kiruiro, 2010). Similarly, interest in renewable energy was as a result of the 1970s oil embargo which resulted in the increase in prices of the petroleum products (Barsky & Kilian, 2004). In addition, environmental protection has augmented the need for alternative sources of renewable energy in Kenya (Kiplagat et al., 2011). Households that use biogas technology contribute 48% less emissions than households without the biogas systems (Rajendran et al., 2012). Health wise, anaerobic digestion treats livestock waste onsite thus reducing the incidents of contamination of waterways due to pathogens and nutrients from human and animal wastes (Rowse, 2011).

The advantages and positive impacts of biogas technology are well documented in previous seminal literature. However, despite numerous social, economic, health and environmental advantages, the biogas technology uptake level remains low in Kenya. The low success rate is as a result of technical, cultural and socio-economic factors (Mwirigi, Makenzi, & Ochola, 2009). In addition, organizational and institutional constraints hinder the adoption and sustainability of the technology especially in the rural areas (Murphy, 2001).

Several gaps on biogas technology in developing countries have been identified. They include lack of long term operation studies on anaerobic digesters, lack of design equations for sizing and designing a small scale anaerobic digester and lack of design criteria for maximizing pathogen reduction in anaerobic digesters (Rowse, 2011).

The aim of this study, therefore, is to assess the success rate of the biogas technology projects and the factors that determine and influence the adoption and sustainability of the technology in the rural Kenya. The outcome will identify under which conditions biogas technology can work best.

1.1 Problem Statement

The purpose of this research is to determine the technical, social, economic, and cultural conditions that affect how the biogas technology can work and function in the best way possible in rural Kenya. A problem statement is aimed at providing the focus and direction of a research. It should describe the problem, state the concepts used in the research, identify the variables to be investigated, and explain the solution to the problem (Derese, 2011).

Kenya currently suffers from the intertwined problems of climate change, food insecurity and energy poverty. Biogas technology has been regarded as a solution to these three problems. According to Sovacool et al. (2015), biogas technology promises to tackle these problems synergistically through mitigating greenhouse gas emissions, improving agricultural sustainability and reducing energy poverty. In addition, according to Mulinda, Hu, and Pan (2013), biogas is multifunctional, offering extra services like "... sanitation, energy recovery, waste management and environmental protection" (p.506). However, adoption and sustainability of the technology is still low, currently at 0.03% of the 1.2 million households with the technical potential to own biogas in Kenya (Tigabu, Berkhout, & van Beukering, 2015).

Biogas technology success in rural Kenya has continued to be problematic in spite of the partnerships with international organisations. Such biogas partnership organisations include Netherlands Development Organization (SNV), Netherlands Directorate General for International Cooperation (DGIS), German Organisation for Technical Cooperation (GTZ), WINROCK International, International Humanist Institute for Cooperation with Developing Countries (HIVOS), Biogas Institute of Ministry of Agriculture, China (BIOMA), African Biogas Partnership Program (ABPP) (Mulinda et al., 2013), International Fund for Agriculture Development (IFAD) and Biogas International (Sovacool et al., 2015).

Although biogas technology has been thoroughly studied in Europe and Asia, little effort has been made to study the same in sub-Saharan Africa (Naik et al., 2014). Lark of biogas advancement is as a result of low access, utilization and maintenance capacity. Similarly, the biogas market potential has been underexploited, despite the technology being linked to poverty alleviation and development in rural areas (Mulinda et al., 2013).

This study investigated the factors that determine the adoption and sustainability (i.e. success rate) of biogas technology in rural Kenya. The study sought to gather information on the physical conditions of biogas digesters, how the biogas technology functions, the feelings and perceptions of the people who have installed the technology, the impact that biogas has on people and whether the rural farmers have the necessary capacity to adopt the biogas technology. It employed both qualitative and quantitative research methods to study biogas technology adoption and success. Research has shown that biogas technology in Africa has been hindered partially by lack and evaluation of data and information. Academicians and government institutions have not fully studied biogas technology due to lack of funds or roadmap (Mulinda et al., 2013). The findings of this research will therefore help to fill the knowledge gap and improve the understanding of the suitable technical, social, economic, and cultural conditions within which the technology can work best in Kenya.

1.2 Research Objectives

The main objective of this study was to identify under which technical, social, economic, and cultural conditions the biogas technology can work best and ensure long-time functioning. In order to achieve this objective, the study carried out a detailed analysis of biogas digester systems that have been installed for more than five years in Kiambu and Meru counties in Kenya.

The specific objectives of this research were:

a) To identify the social and economic status of the households including the land size, the number of livestock, the educational levels and the income.

b) To evaluate the methods used to build, maintain and operate the biogas systems.

c) To assess feelings and perceptions of the people who have installed these digester systems.

d) To find out what impacts the biogas has had on the household members.

Research objectives, both general and specific, summarize what specific goals a research hopes to achieve. Whereas the general objective describes the overall purpose of the research, the specific objectives express the specific result that the research aims to achieve. The objectives must be specific, measurable, achievable, realistic and timely (Derese, 2011).

1. 3 Research Questions

In order to find out which issues need to be addressed regarding biogas technology in rural Kenya, this research was guided by the following key research questions:

a) What are the social, economic, cultural and technical factors that determine the production and use of biogas?

b) What are the success criteria for biogas systems?

c) Under which conditions do biogas systems fail?

According to Bryman (2012), research questions should explicitly guide the researcher on what they are trying to find out. This makes the research become focussed on the specific issues through the whole process. In addition, a research question is a "clear,focused and arguable question around which you plan to center your research. A research question can be answered directly through the analysis of data" (Derese, 2011) p.29.

CHAPTER 2

THEORETOCAL AND CONCEPTUAL FRAMEWORK

2.1 Introduction

This section shall describe and clarify the relationships and connections between different biogas technology concepts and phenomena that are found in theories while at the same time specifically defining the relationships of the variables found in the literature used in this research.

Concepts and theories are defined as "the ideas that drive the research process and that shed light on the interpretation of the resulting findings" (Bryman, 2012) p. 14. Concepts, which are socially constructed, are used to make sense to the social world and are key ingredients of theories. Concepts are used in research to give indicators of the topic being researched while helping the researcher to maintain discipline about what they intend to find out. Concepts also help the researcher reflect upon and organize the data collected. Theories either drive a research in a deductive approach or theories can be a product of a research in an inductive approach. The deductive approach, commonly used in quantitative research, is linear and tests theory in fixed separate stages while the inductive approach, commonly used with qualitative research, is iterative and builds theory through constant interplay and feedback between different stages (Bryman, 2012).

2.2 Biogas Technology Theories and Concepts

Biogas is an alternative source of renewable energy whose raw materials are available and affordable in rural Kenya. Biogas is mainly used for cooking and lighting. In African rural households, cooking accounts for 90% of total energy consumption (Rajendran et al., 2012; Rowse, 2011). Anaerobic digestion is the process through which organic materials are broken down by bacteria, in the absence of oxygen, to produce methane (70%) and carbon dioxide (30%) (Justus K Laichena & Wafula, 1997; Rowse, 2011). Methane (CH_4) is a light, colourless and odourless gas that does not produce smoke (Karanja & Kiruiro, 2010). According to Rowse (2011) "methane has a Global Warming Potential (GWP) twenty-one times greater than the GWP of carbon dioxide" (p. 13).

The table below shows the compounds that biogas is composed of.

Table 1: **Composition of Biogas** *(Sankarlal, 2015) p. 750.*

Compound	Molecular formula	% Content
Methane	CH_4	50–75
Carbon dioxide	CO_2	25–50
Nitrogen	N_2	0–10
Hydrogen	H_2	0–1
Hydrogen sulphide	H_2S	0–3
Oxygen	O_2	0–0

The common feedstock (substrate) materials digested to produce energy in form of biogas are animal and poultry dung, human waste, food waste and agricultural waste. A substrate is defined as "the carbon source electron donor in the biochemical reactions that take place in anaerobic digestion" (Rowse, 2011) p.39. The biogas produced is used for cooking, lighting, heating and running machines, for example, chaff cutter. The residue from the digester is bio-fertilizer called slurry which is rich in nitrogen, phosphorous, potassium and other nutrients, therefore ideal for increased food production and yields (Amigun, Aboyade, Badmos, Musango, & Parawira, 2012).

Biogas technology was introduced in Kenya in 1954 by the white settlers (Justas K Laichena, 1989). However, the mass diversification began in 1980s when 150 units were constructed. The number increased to 800 plants by 2004 (Mwirigi et al., 2009). There was a programme to promote domestic biogas development targeting to install 8000 domestic biogas plants in the rural areas by 2013 (Amigun et al., 2012). Socially, widespread adoption of the biogas technology was hampered by lack of information on its benefits and the high costs of the initial designs (Karanja & Kiruiro, 2010). Technically, failure to achieve the targeted number was due to failures of the initial systems. These failures were as a result of scum forming in the digesters, lack of knowledge on maintenance and operation, wrong feeding of the digesters and incorrect ratio of water and dung mixture. Any single or a combination of these factors reduced gas production (Justas K Laichena, 1989). However, the Kenyan government and Non-Governmental Organisations (NGOs) have been promoting biogas technology through electronic and print media whereas private businesses are commercially installing the digesters by targeting the rural farmers (Mwirigi et al., 2009).

In Kenya, there are three types of biogas digesters that have been introduced in the market. They are the Indian floating-drum, the Chinese fixed-dome and the Plastic tubular digesters (PTD). However, in the recent past, the most adopted types in Kenya are the tubular and the fixed dome digesters (Nzila et al., 2012).

Small scale anaerobic digesters are defined as those producing biogas which is used directly for cooking, lighting, or heating. However, if the biogas produced is used for electricity generation, the anaerobic digester is concidered large scale (Rowse, 2011).

In order to identify under which conditions biogas works best and sustainably, it is necessary to analyse the entire biogas system, factors affecting its productivity as well as its stability. The system is the complete biogas structure beginning from the feedstock until the gas is put into use. Productivity is the quality and the quantity of the biogas generated by the system. Stability is the consistency and the regularity of the gas produced (Naik et al., 2014).

This research used the problem analysis method to find out problems and risks associated with the failure and success of biogas technology systems in order to come up with the appropriate recommendations to improve the technology.

CHAPTER 3

LITERATURE REVIEW

3.1 Introduction

This literature review section includes the relevant previous findings on biogas technology. It is divided in the following sub-sections: situational analysis; installation and operation; the biogas system components, functioning and efficiency; perceptions and benefits; financial analysis; economic analysis; the future of the biogas technology; biogas linked agro-ecosystem; and modern convenient biogas digester.

Literature review is defined as "a critical examination of existing research to the phenomena of interest and of relevant theoretical ideas" (Bryman, 2012) p. 14. It is not just a summary of the literature that has been read, but it should also be critical on the significance and relevance to the thesis. Literature review is necessary in research for various reasons. It enables the researcher to know what has previously been found out and also to avoid mistakes that have been made before by other researchers. The researcher learns different theoretical and methodological approaches to the area of their research while helping them to develop an analytical framework. Literature review can guide the researcher to include new variables he might have forgotten and also give a suggestion of further research questions. It also helps during the interpretation of the findings and identifying how the findings are included in the final paper (Bryman, 2012).

In addition, a comprehensive literature review, which should be selective and critical, provides the reader with the literature related to the problem being investigated. The review assists in evaluating the research idea against the larger context of what has been found before. It further demonstrates that the current research will fill a crucial gap in what is missing in the available research findings on that particular field (Derese, 2011).

3.2 Situational Analysis

In Africa, biogas technology has not been studied thoroughly as compared to Europe and Asia (Naik et al., 2014). This is due to of lack of funds and a road map for the development of the technology (Mulinda et al., 2013). In addition, high installation costs, lack of information on biogas benefits and organisational and institutional constraints have also hampered its adoption (Karanja & Kiruiro, 2010; Murphy, 2001; Rajendran et al., 2012). The average installation costs for a standard $8m^3$ is 750 Euros (Ghimire, 2013). Despite the high installation costs, operation costs of biogas systems is low (Sovacool et al., 2015; Ullrich, 2008).

Consequently, only 0.03% of Kenyan households with the technical potential have installed biogas systems (Tigabu et al., 2015). This is in spite of the numerous NGOs, development organisations and the government of Kenya promoting the technology in the rural areas (Mulinda et al., 2013; Mwirigi et al., 2009; Sovacool et al., 2015). These promotional programmes have been unable to reach the projected adoption numbers (Amigun et al., 2012; Justus K Laichena & Wafula, 1997; Mwirigi et al., 2009).

Recent research has shown that, people who are more likely to adopt new technology have medium and high education levels (Bond & Templeton, 2011; Roubík, Mazancová, Banout, & Verner, 2016). Similarly, most rural farmers have the potential to install the systems since they have adequate land and livestock which are the main factors necessary for biogas production (Day et al., 1990; Omiti et al., 2009). A minimum three cows are required to produce enough cow dung for a standard biogas digester (Ghimire, 2013).

Research has shown that anaerobic digestion has numerous benefits as summarized in the table below.

Table 2: Benefits of Anaerobic Digestion in Developing Countries *(Rowse, 2011) p.4.*

Benefits of anaerobic digestion for developing country applications	**Explanation**
Improved indoor air quality	Combustion of solid biomass cooking fuels results in high levels of particulate matter in the indoor microenvironment. Particulate matter causes respiratory infections in children, adverse pregnancy outcomes, chronic lung diseases and heart diseases, and cancer.
Energy production in the form of biogas, which can be used as a cooking fuel	Anaerobic digestion is a net-energy producing process. Biogas, similar to natural gas, produces very little air pollution when combusted.
Provides an alternative to unsustainable deforestation	One cause of deforestation is the use of wood fuel for cooking and lighting. Introduction of household anaerobic

	digesters and the use of biogas for cooking reduce wood fuel use and therefore reduce deforestation.
Provides treatment of human and/or animal waste	Prevents nutrient runoff into water basins which drain to ocean environments, creating environmental problems. Prevents possible diarrheal disease downstream.
Empowers women	Women and girls typically spend more time indoors cooking, and therefore, have a disproportionate exposure to indoor air pollution from combustion of solid biomass fuels. They are more likely to develop chronic health problems related to exposure to particulate matter.
The amount of bio solids to be disposed is smaller than the amount resulting from aerobic treatment processes	Most of the energy input into the anaerobic digester in the form of raw wastewater is converted to CH_4 and CO_2. Relatively little energy goes to cell growth.
Nutrient- rich effluent may be used as a fertilizer for crops	Commercial fertilizers are expensive and the processes for making them are unsustainable. Nitrogen and phosphorus are nutrients excreted from the human body in the form of faeces and urine. Effluent from anaerobic digestion contains nitrogen and phosphorus which may be used as a fertilizer for agricultural crops.
Mitigation of methane and carbon black emissions into the atmosphere	Methane has a Global Warming Potential twenty-one times greater than carbon dioxide. Black carbon particles absorb radiation and cause warming of glaciers by reducing light reflection.

3.3 Installation and Operation

In Kenya, there are three common types of biogas digesters. These are the fixed dome, the floating dome and the tubular plastic digesters (Nzila et al., 2012; Rowse, 2011). The common sizes for these digesters are 4,6,8,10 and 12 m^3 (Ghimire, 2013). The main components of the biogas system and the installation materials required are well defined by previous researchers (Cheng et al., 2014; Mulinda et al., 2013; Rajendran et al., 2012; Ullrich, 2008). The spherical shape of the biogas digester has been described as having more stability than any other shapes (Justus K Laichena & Wafula, 1997). However, in developing countries, there lacks adequate information on design methods for biogas systems (Rowse, 2011).

The fixed dome biogas digester combines both the gas storage dome and the digestion chamber as a single unit (Mulinda et al., 2013). A complete biogas system is composed of five sections, namely, the structural components, the piping system, the biogas utilization system, the effluent disposal system and the anaerobic digestion system (Cheng et al., 2014). The biogas digester site should not be near trees because the roots can damage the digester (Ullrich, 2008). The materials used to install a biogas system primarily depend on the geological and hydrological soil properties, and the local availability of the construction materials (Rajendran et al., 2012).

The main components of a fixed dome biogas system are as per the figure below.

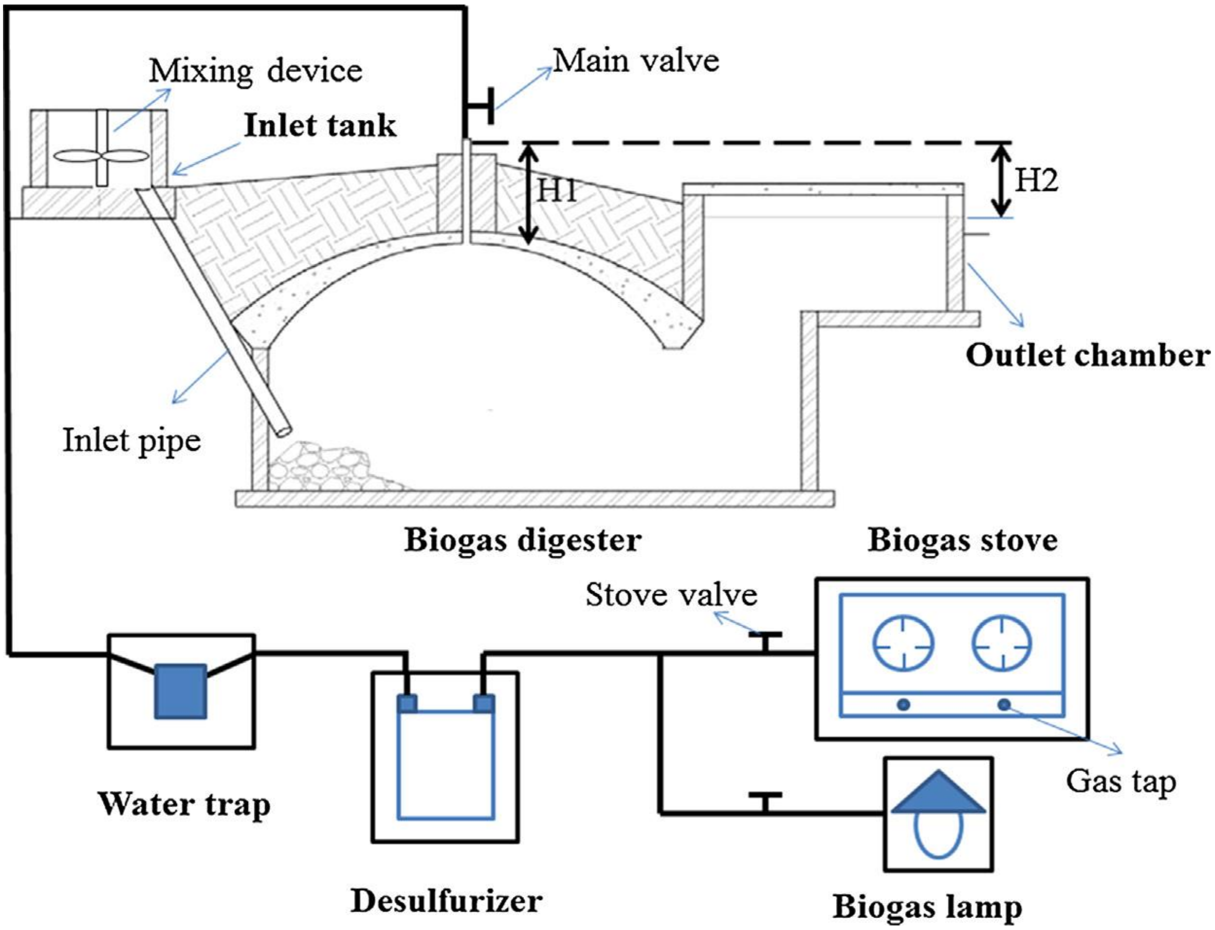

Fig. 1: The Fixed Dome Biogas System *(Cheng et al., 2014)p. 1374.*

Cow dung has been found to be the best component of the substrate. Fresh cow dung is better than dry cow dung. The mixture ratio of dung and water should be1:1 (Abubakar & Ismail, 2012; Day et al., 1990; Rajendran et al., 2012).

The figure below shows the biogas yields from dry and fresh manure.

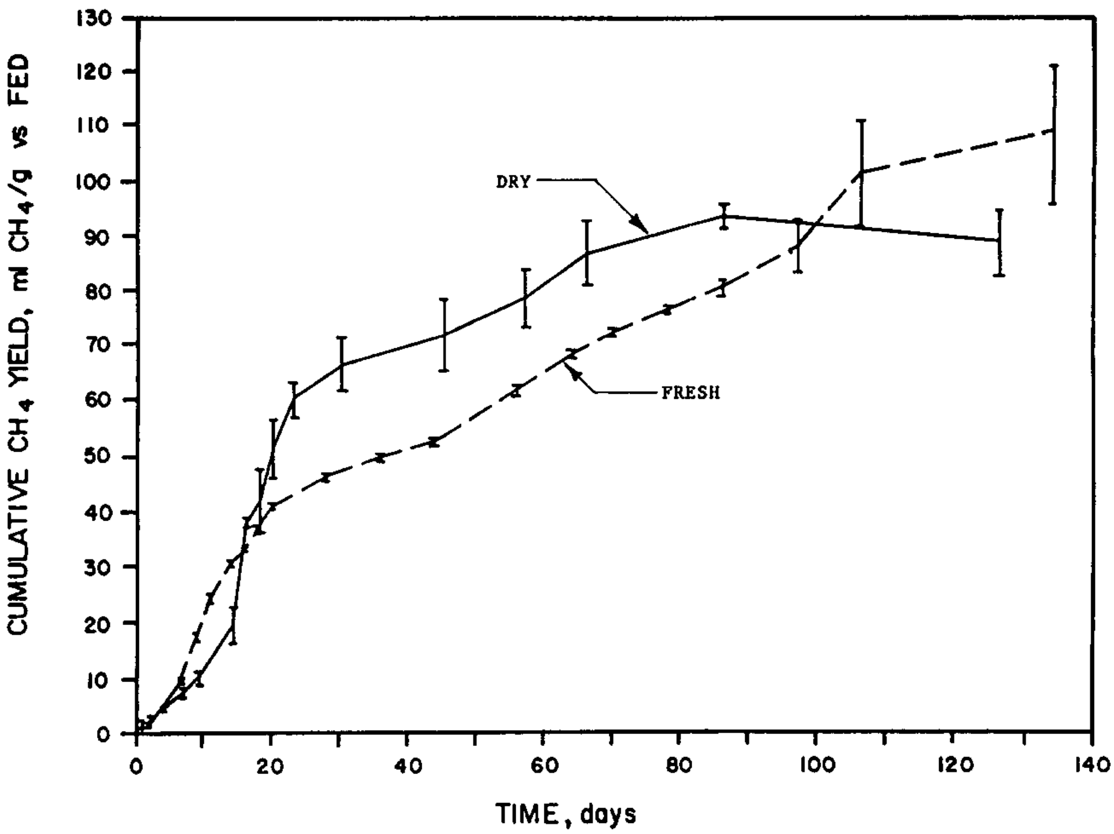

Fig. 2: Comparison of methane yields from dry and fresh daily manure *(Day et al., 1990) p. 89.*

The quantity of the feedstock fed in the digester should reach the bottom of the outlet chamber (Rajendran et al., 2012). A minimum of 20kgs of cow dung is recommended to feed an average household digester daily (Ghimire, 2013). Geothermal temperature helps maintain the temperature of the substrate (Abubakar & Ismail, 2012; Rajendran et al., 2012).

Adequate biogas production starts after six days and continues to increase exponentially as the number of the methanogenic bacteria continues to grow (Abubakar & Ismail, 2012).

The figure below shows the gas production which increases with time.

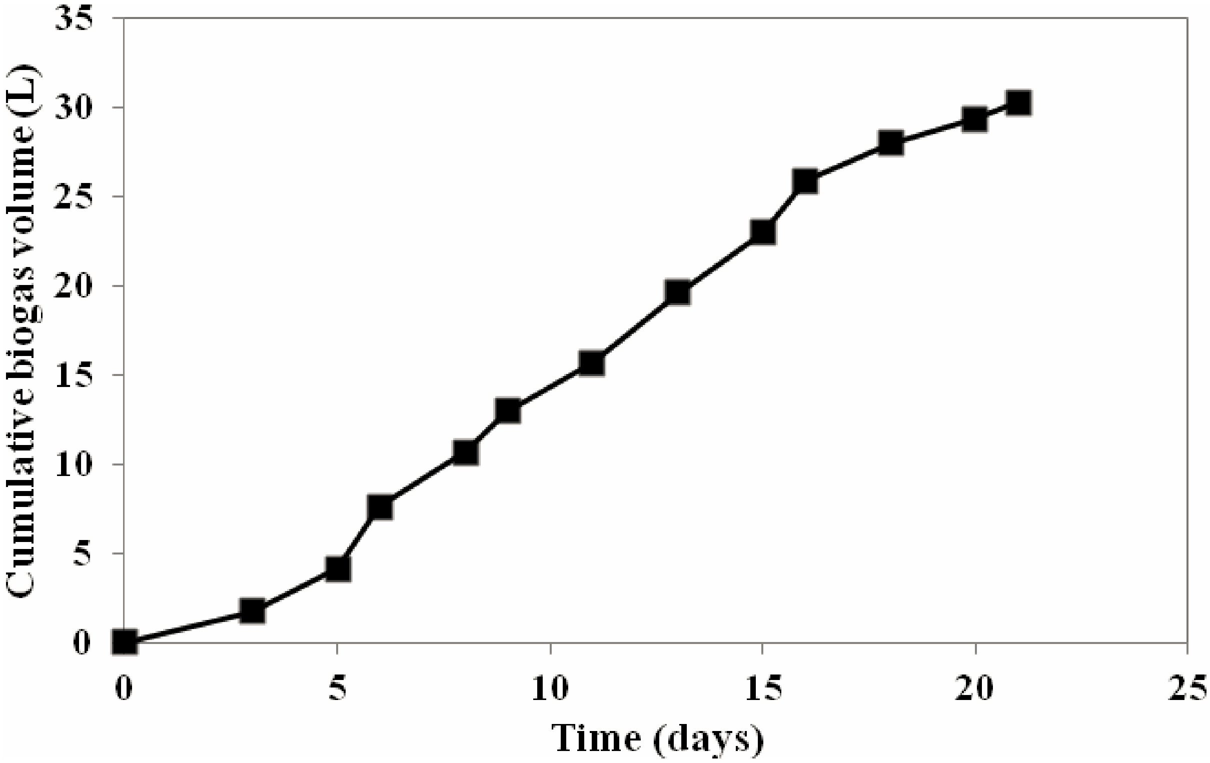

Fig. 3: Cumulative biogas production *(Abubakar & Ismail, 2012) p. 170.*

Anaerobic digestion occurs in three microbiological processes namely fermentation, acidogenesis, and methanogenesis. The first process (fermentation), involves fermentative bacteria that excrete enzymes that break down macromolecules in the substrate. The compounds are broken down by the bacteria into simpler forms produces a mixture of organic acids, hydrogen, and carbon dioxide. The second process (acidogenesis), involves oxidizing of the organic acids produced during fermentation by the fermentative bacteria. Ethanol, hydrogen, and carbon dioxide are produced at this stage. The third process (methanogenesis), involves hydrogen and carbon dioxide forming into methane. (Rowse, 2011).

The figure below shows the anaerobic digestion process.

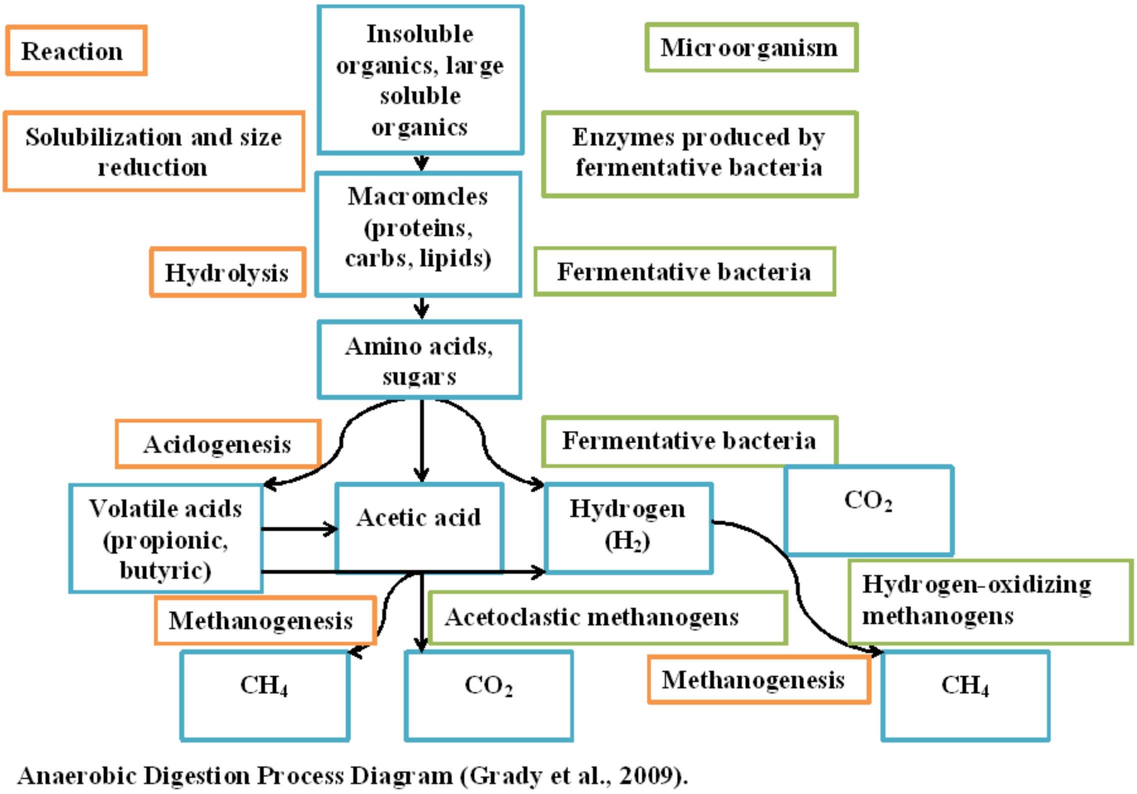

Fig. 4: Anaerobic Digestion Process. *Rowse (2011) p.21.*

Hydraulic retention time (HRT) is the length of time the substrate remains inside the digester for anaerobic digestion before being discharged through the outlet. There are two conflicting findings of the hydraulic retention time of the substrate in the digester. On one hand, Justus K Laichena and Wafula (1997) suggests a period of 90 days while Rajendran et al. (2012) argues that it should be 10-15 days. Such a big difference is as a result of the size or the volume of the digester, such that the larger the volume, the longer the hydraulic retention time.

The following formula is used to calculate the HRT of a biogas digester. Source: Rowse (2011) p.42.

$$\theta = \frac{V}{Q}$$

where: θ = hydraulic retention time (days)

V = volume of the digester (m^3)

Q = influent flow rate

In addition, the inlet and the outlet should be directly opposite to each other to ensure that the substrate is fully exhausted during the HRT before exiting the digester (Ullrich, 2008).

Several studies have established that co-digestion increases biogas production than mono-digestion. Molasses, talinum traianglaire and charcoal are used for co-digestion purposes (Ebuniloa, Owunnaa, Sadgerea, Ukwagbab, & Orhorhoroc, 2015; Kumar, Jain, & Chhonkar, 1987; Rajendran et al., 2012; Sarker & Møller, 2013)

3.4 Biogas System Components, Functioning and Efficiency

Faults in biogas technology have attracted a great deal of interest in the recent years. Faults in the biogas systems are found in five main subsystems namely structural components, biogas utilization equipment, piping system, biogas production and effluent disposal system (Cheng et al., 2014). Subsequent study has given recommendations on how these subsystem faults can be rectified (Roubík et al., 2016).

The table below further explains the main failures and inefficiency indicators of biogas technology subsystems.

Table 3: Failures of biogas subsystems *(Cheng et al., 2014)p. 1375.*

Subsystem	Failure and inefficiency indicators
Structural components	1. Inconvenient position of plant components. Relative positioning of plant components are not appropriate, e.g., plant is too far from animal shed; inlet tank is too high for feeding; outlet tank is too remote to be reached 2. Unsuitable inlet pipe slope. Cleaning the inlet pipe with a long stick is impossible when the inlet pipe is blocked during feeding because the long stick will be hindered by the wall 3. Broken/missing mixing device. In such case, the dilution of raw materials is difficult, therefore feeding is difficult 4. Cracks in structural components. Big crack(s) on the wall of the inlet tank or outlet chamber because the construction quality is poor or the chamber is damaged by natural disasters such as floods
Biogas utilization equipment	1. Malfunction of biogas stove. Flame pedestal is broken; gas tap is broken; air injection ring is rusty or broken; air injection hole is blocked or too big to adjust gas consumption or flame. 2. Inoperative biogas lamp.
Piping system	1. Leakage of piping system. The valve is defective. The valve is a water valve instead of a gas valve. The connections between the valve and the pipe, or between the pipe and the nipple, are not fixed. The gas pipeline is

	corroded after a long time. The clamp for fixing the connection is missing 2. Blockage of piping system. If the biogas pipeline is too long or overhanging, and if no water trap is available, then water may be condensed within the pipe
Biogas production	When daily biogas production is less than half of the designed standard capacity, failure is taken into consideration 1. Leakage of biogas in digester due to pressure inside the digester. 2. Thick scum layer on the surface prevents biogas from escaping 3. Breakdown of anaerobic digestion process. Several parameters affect normal anaerobic digestion process, such as unbalanced carbon to nitrogen ratio, too-high or too-low pH value, low temperature, less feedstock, and existence of inhibitor 4. Not enough feedstock.
Effluent disposal system	1. The outlet pipe is blocked. 2. Biogas slurry is discharged without environmental control, e.g., into a body of water without any disposal treatment 3. Unsuitable effluent disposal. The slurry is only stored as waste without being reuse as organic fertilizer. Slurry is applied onto farmlands directly without composting or stabilization

Faults affect the biogas systems, their productivity and stability. The reasons for such faults are lack of adequate knowledge on operation of the systems and the mixture ratio of the feedstock (Justus K Laichena & Wafula, 1997; Naik et al., 2014). In addition, leakage also reduces biogas reaching the point of use. Such leakage areas should be checked by applying soap foam in the piping system and observe where bubbling appears and then seal the leaks (Ullrich, 2008). Faults, which can be caused by the lack of repair and maintenance, can ultimately lead to failure of the biogas system. Failure occurs when biogas production is less than 50% (Bond & Templeton, 2011; Cheng et al., 2014).

Recent research done gave recommendations and possible solutions to biogas system failures as per the table below.

Table 4: Failures and recommended solutions for biogas technology *(Roubík et al., 2016) p.2787.* Note: BGP means Biogas Plant.

Subsystem	**Failure description**	**Recommendation, possible solutions and notes**
Structural components	• Problems with the inlet pipe • Unstable BGP in rainy season • Inconvenient position of	• Clean the inlet pipe with stream of water • Appropriately selected BGP and higher skills from masons • The BGP is too far from animal sheds, the inlet

	BGP components	pipe is at an inappropriate slope, the outlet tank is too remote to be reached.
Piping systems	• Leakage in piping system • Blockage of piping system	• When the pipe is not connected adequately. The connections between the valve and the pipe or between pipe and nipple are not working properly. The gas pipe is corroded. When necessary, the pipe line should be replaced or repaired by facilitators/masons. • When the pipe line is overhanging for long time, and if no water filter is available water may be condensed within the pipe. Use of a water filter and regular use
Biogas utilisation equipment	• Malfunction of biogas cooker	• Malfunctions of biogas cooker are diverse in origin such as corrosion, a broken gas tap, and a broken flame pedestal or a blocked air injection hole. Corrosion can be reduced with a H2S filter.
Digestate disposal system	• Poorly accessible reservoir for digestate • Lack of organic matter in digestate	• When the reservoir is inappropriately located, it creates difficulties with further digestate management. • High water levels. Knowledge should be transmitted via local facilitators
Anaerobic Digestion process and biogas production	• Leakage in reactor • Solid digestate incrustation >floating in the main tank • Lack of biogas • Poor quality of biogas • Smell of biogas	• When the digester is not made properly, the pressure from inside the digester pushes the gas out. It can lead to the elimination of the functionality of the BGP. Masons must be skilled enough to avoid problems with digester. In cases of significant leakages, the BGP must be fully rebuilt. • A scum layer on the surface preventing biogas from going through it. The BGP must be opened and cleaned • Can be caused by the poor quality of biogas (a slow concentration of methane), or by a lack of organic matter. Can also be caused by process breakdowns. • The quality of biogas depends on the individual components and its methane concentration. This is affected by temperature, the presence of oxygen, feedstocks, hydraulic retention time etc. • Any bad smell from biogas can be removed by the use of a H2S absorbent.

	• Lack of feedstock/Over-size of BGP • Breakdown of anaerobic digestion process • Oversupply of biogas	• When farmers reduce the number of animals, there are no longer appropriate amounts of manure. • There are many parameters affecting the AD process, such as: an inappropriate pH, low temperature and large temperature fluctuations, and the existence of inhibitors. Inhibitors can originate from inappropriate cleaning chemicals in pig-pens, feeding additives like growth hormones, antibiotics and heavy metals. • Consequences are because of farmers releasing biogas into the atmosphere: making a contribution to the GHG due to the presence of methane.
Knowledge related problems	• Lack of knowledge by owners, masons and facilitators	• There is need for a functioning transmission of information from the large-scale level via local facilitators to the target group of BGP owners

Age of the biogas systems also determine the efficiency in biogas production. As the systems ages, so does the frequency of leakages and failures which reduce biogas production. Recent designs have been observed to perform better than the older ones (Amjid, Bilal, Nazir, & Hussain, 2011; Bond & Templeton, 2011; Cheng et al., 2014; Justus K Laichena & Wafula, 1997).

Biogas production is also determined by the substrate temperature. Several studies have been conducted on the appropriate temperature for the best biogas production (Bond & Templeton, 2011; Clemens, Trimborn, Weiland, & Amon, 2006; Ebuniloa et al., 2015; Karanja & Kiruiro, 2010; Rajendran et al., 2012; Sankarlal, 2015). There are two main temperature zones, namely mesophilic zone (20-40ºC) and thermophilic zone (above 40ºC). It has been determined that the best substrate temperature zone for biogas production is between 32-40°C, the range where the bacteria grow best (Bond & Templeton, 2011). The temperature inside the biogas digester determines the amount of biogas that is produced (Clemens et al., 2006). Whereas the bacteria work best between 20-40ºC, optimal biogas production occurs at the ambient temperature of 35-40ºC, and production ceases at 10ºC. Biogas systems are therefore not ideal in cold areas (Karanja & Kiruiro, 2010). Research shows that gas production increases ten times when the temperature increases from 10 to 25 ºC (Rajendran et al., 2012). However, when temperature changes abruptly, for microorganisms to adapt to the change in the temperature in the substrate, it takes a minimum of three weeks (Rajendran et al., 2012). A thermometer should be used to monitor the temperature in the digester (Ebuniloa et al., 2015).

The figure below shows the temperature range for optimal growth of bacteria.

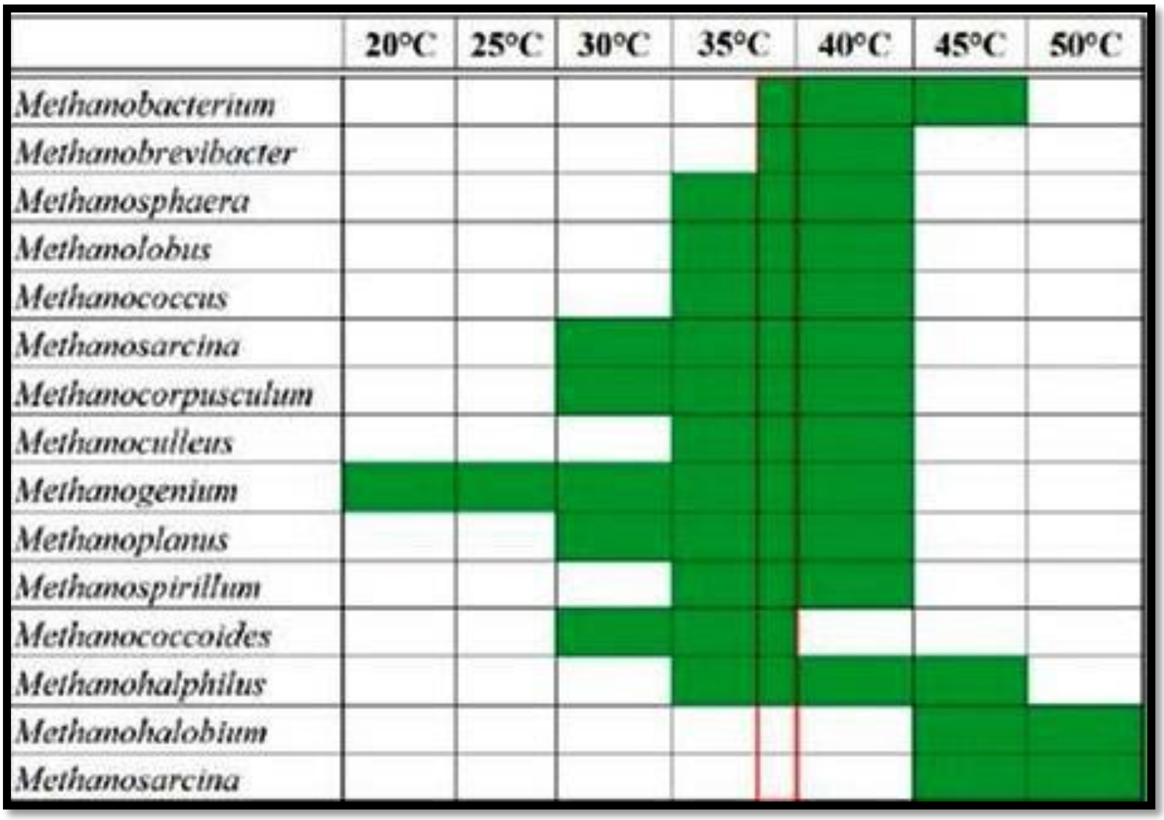

Fig. 5: Temperature range for optimal growth of bacteria therefore showing the maximum gas production at between 35-40°C *(Sankarlal, 2015) p.750.*

Research has shown that the pH determines both the stability of the substrate and the quantity of the biogas produced. Further studies have shown that the best pH range for biogas production is between 6.5-7.5. Cow dung is the best raw material because it has a pH of 7.4 and therefore, it does not need pH regulation because it is already at an optimal p.H. In addition, cow manure has methanogenic bacteria necessary for biogas production (Abubakar & Ismail, 2012; Bond & Templeton, 2011; Bouallagui, Cheikh, Marouani, & Hamdi, 2003; Labatut & Gooch, 2012).

The figure below shows the pH profile during anaerobic digestion of cow dung. The first few days has a sharp reduction of the pH due to the high volatile fatty acid which, however, stabilises with time to the optimum levels (Abubakar & Ismail, 2012).

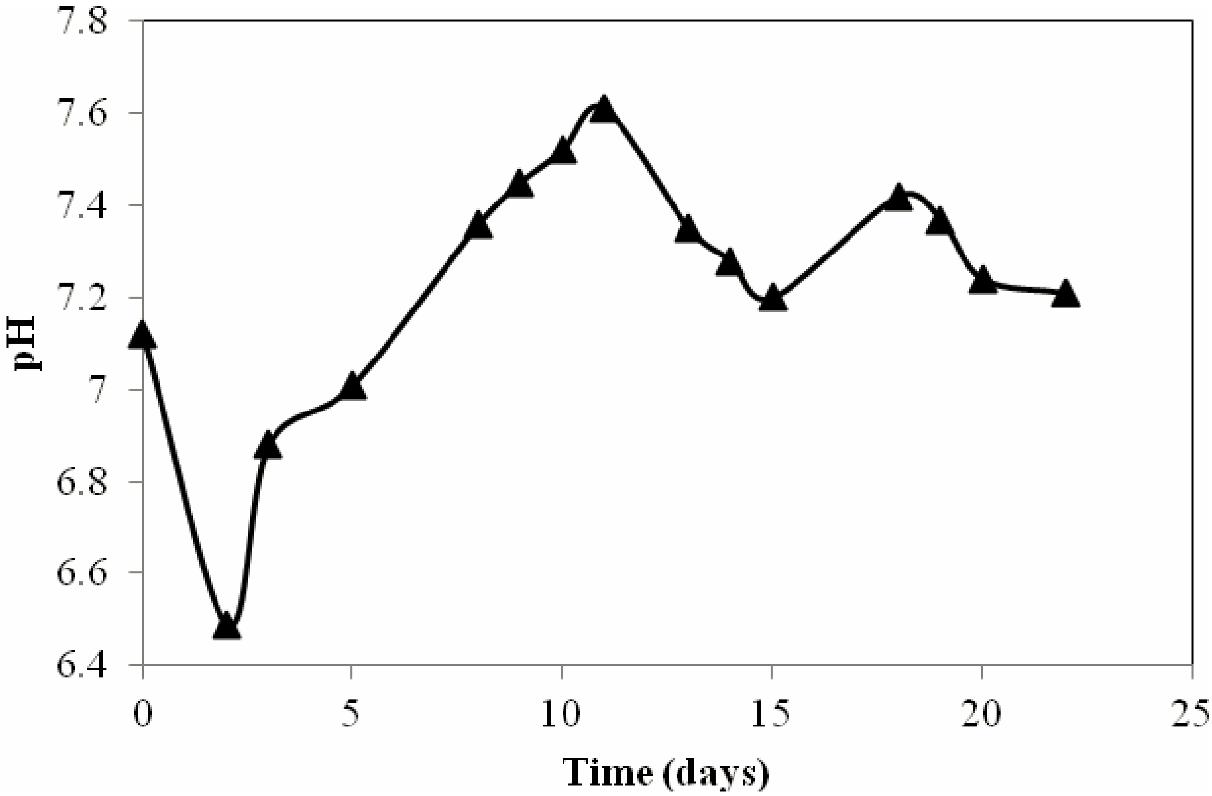

Fig. 6: The pH profile during anaerobic digestion of cow dung *(Abubakar & Ismail, 2012) p. 170.*

Water condensation in the pipes reduces and slows down, or even stops the gas flow. This condensed water has to be removed using a water trap. Removal of the condensed water is, however, not necessary if the piping system is straight and at a sloping angle from the digester to the point of use, because such condensed water will flow right back into the digester. Similarly, gas flow is affected by the scum that forms on top of the substrate. According to Rowse (2011), the scum is formed by the rising gas lifting particles, grease, oil, and fat molecules. To remove this scum, the substrate should be stirred regularly. However, excessive stirring stresses the methanogenic bacteria, while less stirring results into further formation of more scum (Cheng et al., 2014; Justus K Laichena & Wafula, 1997; Rajendran et al., 2012; Rowse, 2011; Ullrich, 2008).

It has also been noted that bacteria cling to digester surfaces and hence the need to regularly stir the substrate (Wilkie, 1998). Stirring is said to "increases the rate kinetics of anaerobic digestion, accelerating the biological conversion process. Additionally, mixing allows uniform heating of the reactor " (Rowse, 2011) p. 46. Besides, for best functioning, the substrate should be replaced twice a year (Ebuniloa et al., 2015).

Biogas needs to be mixed with oxygen for combustion. Two studies presented conflicting results on the ratio between biogas and oxygen. In the first case, Rajendran et al. (2012) found that one litre of biogas should be mixed with ten litres of oxygen, while in the second case, Cheng et al. (2014) recommended that one litre of biogas should be mixed with six litres of oxygen.

Different flame colours are indicators of the condition of the biogas being produced. The flames are either yellow or blue in colour. For a properly functioning biogas system, the flame colour should be blue (Rajendran et al., 2012). A yellow flame is an indicator that the biogas being delivered is not enough while a blue flame indicates the biogas is enough (Ebuniloa et al., 2015). These two findings contradicts with the findings by Bakar et al. (2015) who argued that the flame changes from yellow to blue as it becomes hotter.

Biogas is an efficient and effective alternative source of energy. According to the Cambridge University Press (2017), efficiency means the condition of producing the results without waste. Compared to other sources of energy, biogas has a heat efficiency of 57%, only comparable to LPG gas. The biogas lamp light emission is equivalent to up to a 75W bulb (Justus K Laichena & Wafula, 1997; Rajendran et al., 2012). Biogas combustion can produce mechanical and electric energy (Goud, Karthik, Sudarshan, & Kumar, 2016; Rajendran et al., 2012). However, further research on the conversion and effectiveness of biogas to mechanical and electric energy needs to be studied further (Sankarlal, 2015).

Desulphurization is necessary before using biogas. When hydrogen sulphide is not filtered from biogas, internal combustion leads to corrosion. Exposure to hydrogen sulphide also leads to health problems (Baspinar, Turker, Hocalar, & Ozturk, 2011; Rajendran et al., 2012; Sankarlal, 2015).

3.5 Perceptions and Benefits of Biogas

Biogas benefits include time and money saved, reduced workload, health and quality of life. Women are the main beneficiaries within a family (Amjid et al., 2011; Ghimire, 2013; Justus K Laichena & Wafula, 1997; Rajendran et al., 2012; Sankarlal, 2015; Sovacool et al., 2015). In the rural areas, 90% of energy is used for cooking. Women are normally responsible for cooking (Rajendran et al., 2012; Rowse, 2011). When rural households use biogas, firewood consumption decreases on average by 53% (Rowse, 2011).

The figure below shows the nexus between women and biogas in a rural household setting.

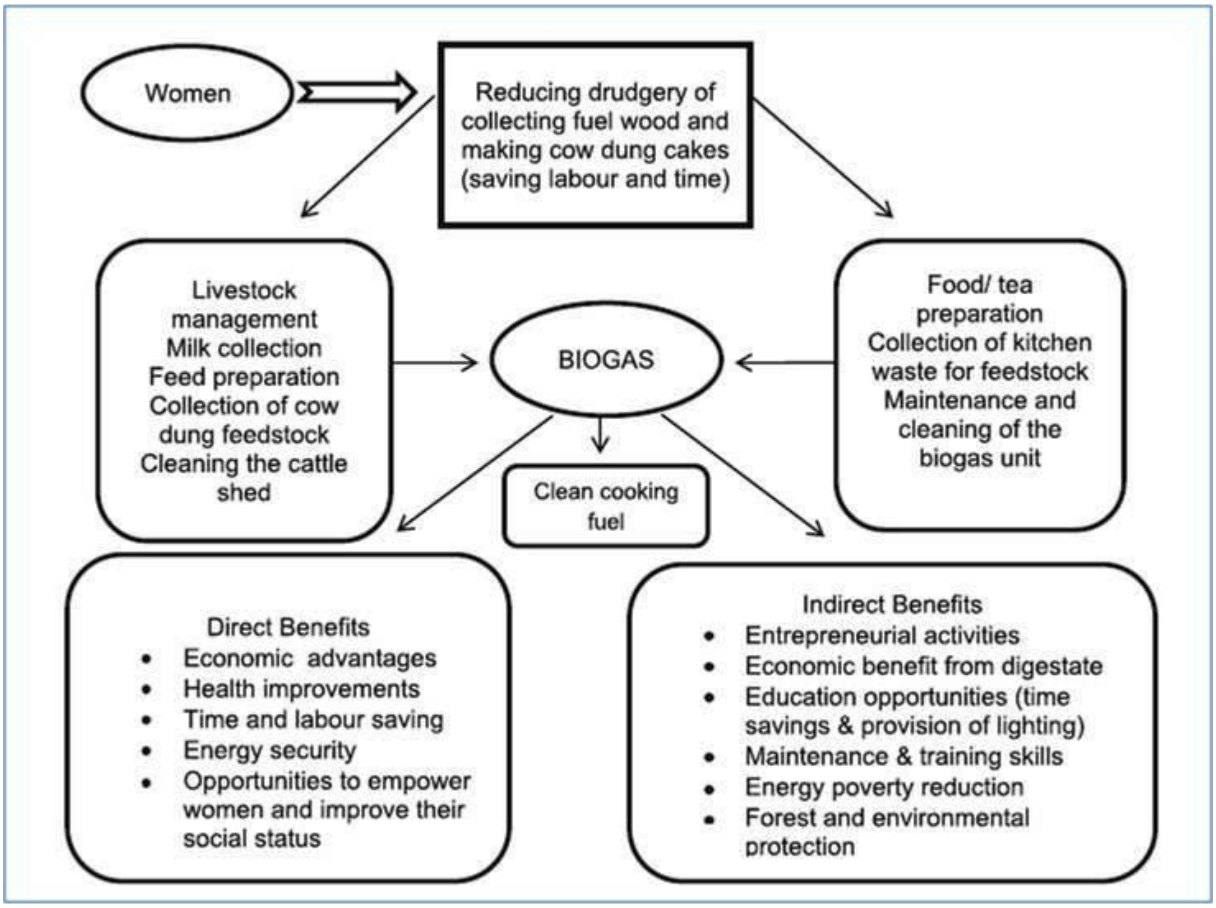

Fig. 7: Role of women in feeding, maintaining and usage of household biogas systems *(Sankarlal, 2015) p. 752.*

Biogas technology has no concretely defined market value. This is because, the biogas market potential has not been fully exploited. Nevertheless, biogas is a multifunctional product. It synergistically solves multiple problems related to climate change, food insecurity and energy poverty (Bond & Templeton, 2011; Mulinda et al., 2013; Sovacool et al., 2015). There are contradicting annual financial savings from using biogas instead of the traditional sources of energy in the rural areas. Sovacool et al. (2015) found out that a family saves $204 annually while Karanja and Kiruiro (2010) found out that such a family saves $342 annually.

Chemical fertilizers consume a lot of energy to produce and are expensive for rural farmers (Rowse, 2011). The figure below shows the substitute revenues of using biogas for an entire lifespan of a biogas plant, with most savings being derived from using slurry as a substitute to nitrogen and phosphate fertilizers.

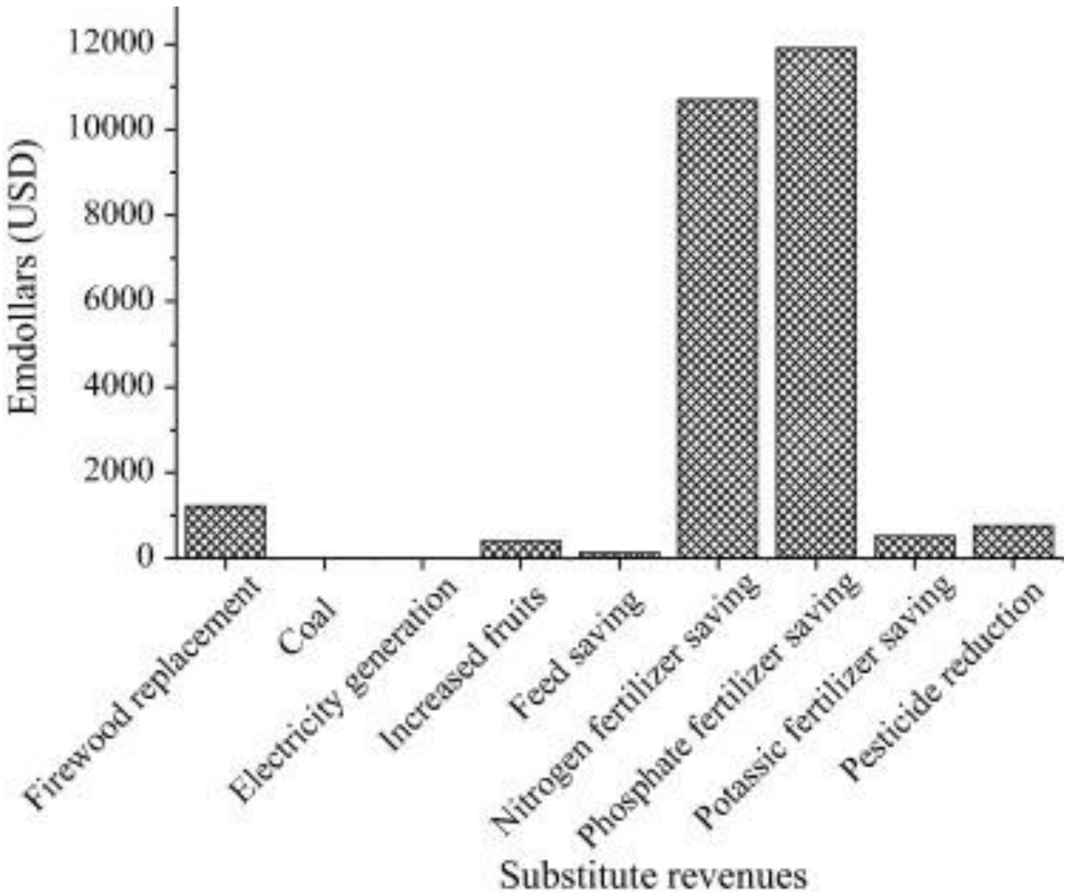

Fig. 8: Substitute revenues of using biogas *(Zhang & Chen, 2017)p. 826.*

Slurry also increases algae growth in a fish pond which the fish feed on, thus increasing fish production (Adeoti, Ilori, Oyebisi, & Adekoya, 2000; Amigun et al., 2012; Ariga, Jayne, Kibaara, & Nyoro, 2008; Bouallagui et al., 2003; Cheng et al., 2014; Dahiya & Vasudevan, 1986; Food and Agriculture Organization, 1992; Goud et al., 2016).

A comparison has been made in a previous study to identify the energy inputs and outputs of a functioning biogas system (Sovacool et al., 2015).

The figure below shows the energy inputs and the outputs of a biogas system.

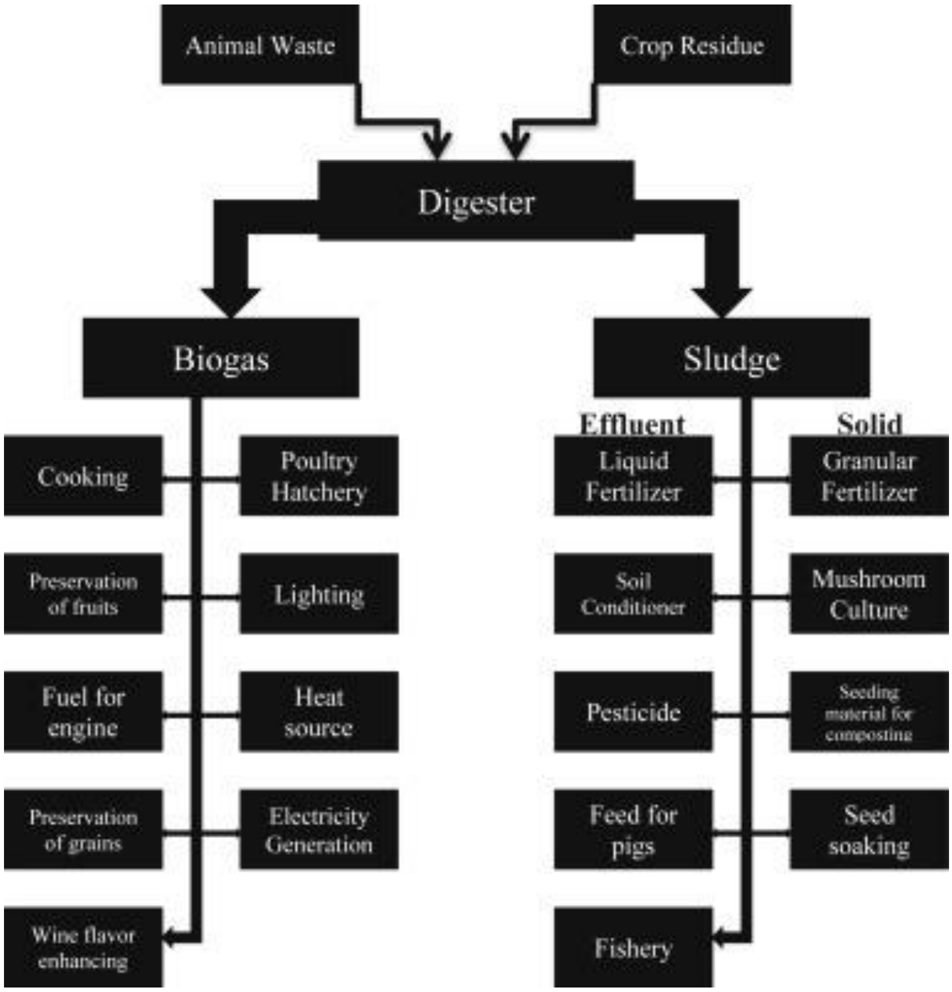

Fig. 9: Energy service functionality of a biogas system *(Sovacool et al., 2015) p.119.*

3.6 Financial Analysis

Cost/benefit analysis is important in order to assess the economic profitability of biogas. This is done by calculating the cost/benefit ratio. The project becomes viable if the benefits are more than the costs. The biogas system costs include installation, annual expenditure, desulphurizer and operations and maintenance costs (Adeoti et al., 2000; Pöschl, Ward, & Owende, 2010). Additionally, it is necessary to work out the payback period of the biogas technology. This is determined by the time taken to repay the costs incurred by adopting the technology (Roubík et al., 2016). Another factor to consider is the net present value of the technology (NPV). The NPV is the present value of the benefits minus the present value of costs (Adeoti et al., 2000).

3.7 Economic Analysis

The economic analysis is done by assessing the overall costs and benefits for the wider society from adopting the biogas technology. Economic benefits are not necessarily equivalent to financial benefits. Biogas has economic benefits in terms of cleaner environment, conservation of forests, increased food production, reduced carbon emissions/global warming, improved health, economic growth, poverty alleviation, increased employment opportunities, more free time for women, increased happiness due to better lifestyle and food security (Rajendran et al., 2012; Roubík et al., 2016).

The figure below shows the environmental and social benefits derived from using biogas.

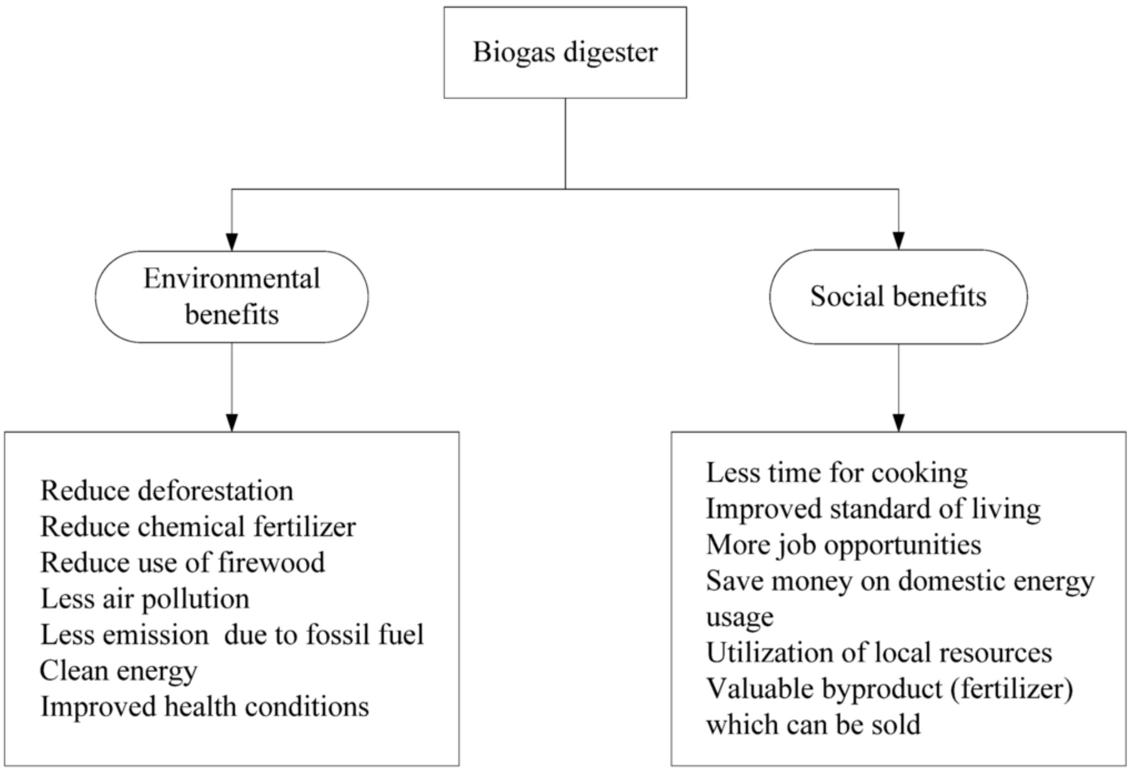

Fig. 10: Environmental and social benefits of using biogas (*Rajendran et al., 2012) p.2930.*

Four major illnesses due to indoor smoke exposure are respiratory infections in children, adverse pregnancy outcomes, chronic lung and heart diseases, and cancer. On average, women in developing countries spend three-fifths of their time indoors, especially in the kitchen, and are therefore disproportionately exposed to smoke particulate matter in comparison to men. As household socioeconomic status increases, fuel types that are less polluting to the indoor environment become more prevalent. This is termed to as climbing the “energy ladder” (Rowse, 2011) p.8.

The figure below shows the percent reduction in health problems due to using biogas. Women experience the most reduction of all diseases.

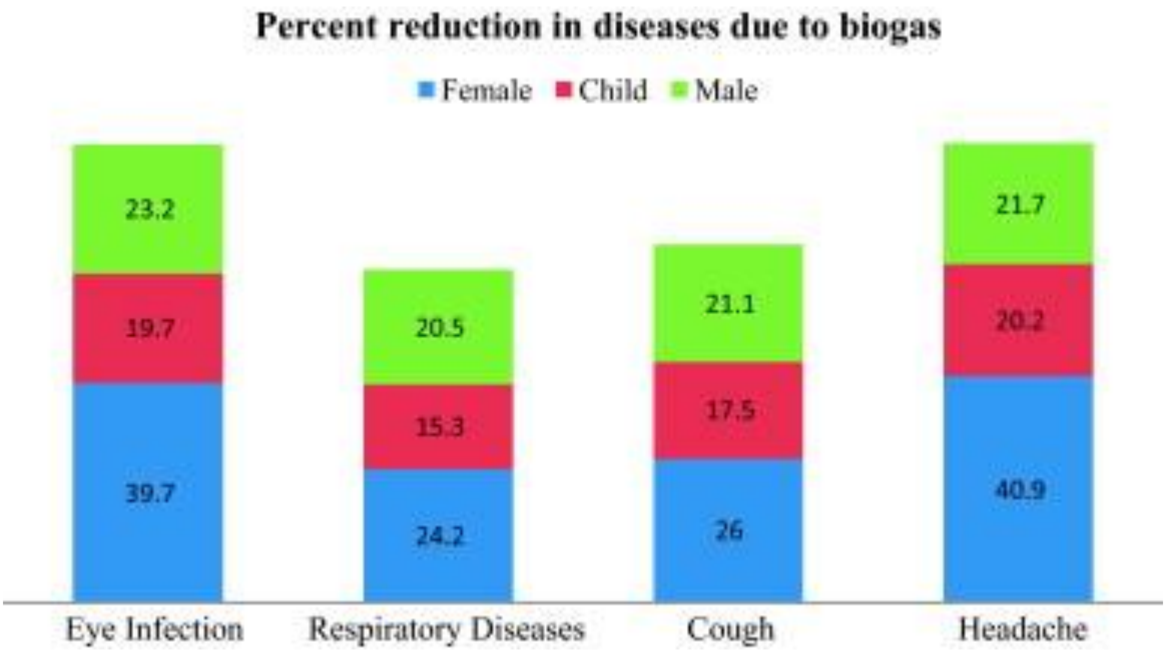

Fig. 11: Percent reduction in diseases due to biogas *(Amjid et al., 2011) p. 2835.*

3.8 The future of biogas technology in Kenya

Biogas promises to offer social, environmental, financial and economic benefits (Rajendran et al., 2012). It can be upgraded and used as vehicle fuel (Ghimire, 2013; Pöschl et al., 2010; Sankarlal, 2015; Venkatesh & Elmi, 2013).

The figure below illustrates the future potential of biogas technology.

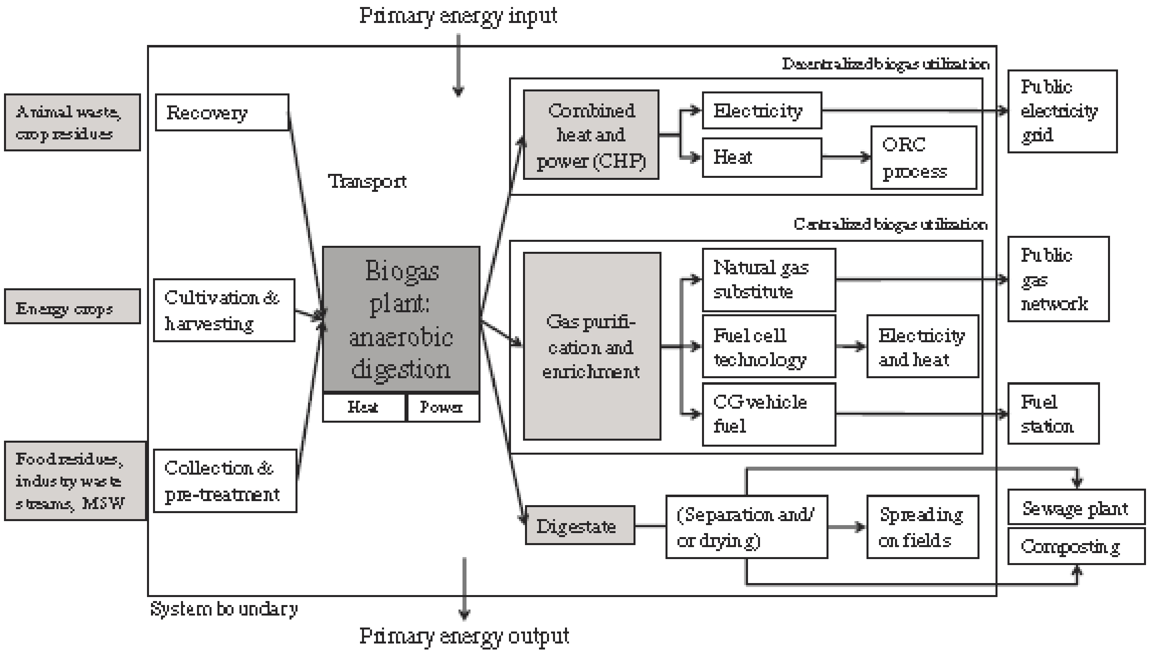

Fig. 12: The potential of biogas technology *(Pöschl et al., 2010) p.3307.*

3.9 Modern Convenient Biogas Digester

In 2011, The Norwegian Institute of Bioeconomy Research, NIBIO, (formerly Bioforsk), carried out a research in China, to find out if there exists more modern and convenient biogas digesters than the traditional fixed dome and the floating dome digesters made of brick and concrete. The outcome of the research recommended the fibreglass digester which could work well in Africa and other tropical countries.

The fibreglass digester is manufactured by filling resin solution into a mould (a hollow flame) which gives the digester the required shape as the resin solidifies. All the digesters are therefore standard in weight, shape and size. They are tested for air tightness and for guaranteed quality control before being released to the market.

The figure below shows the manufacturing flow chart of the Chinese fibreglass biogas digester.

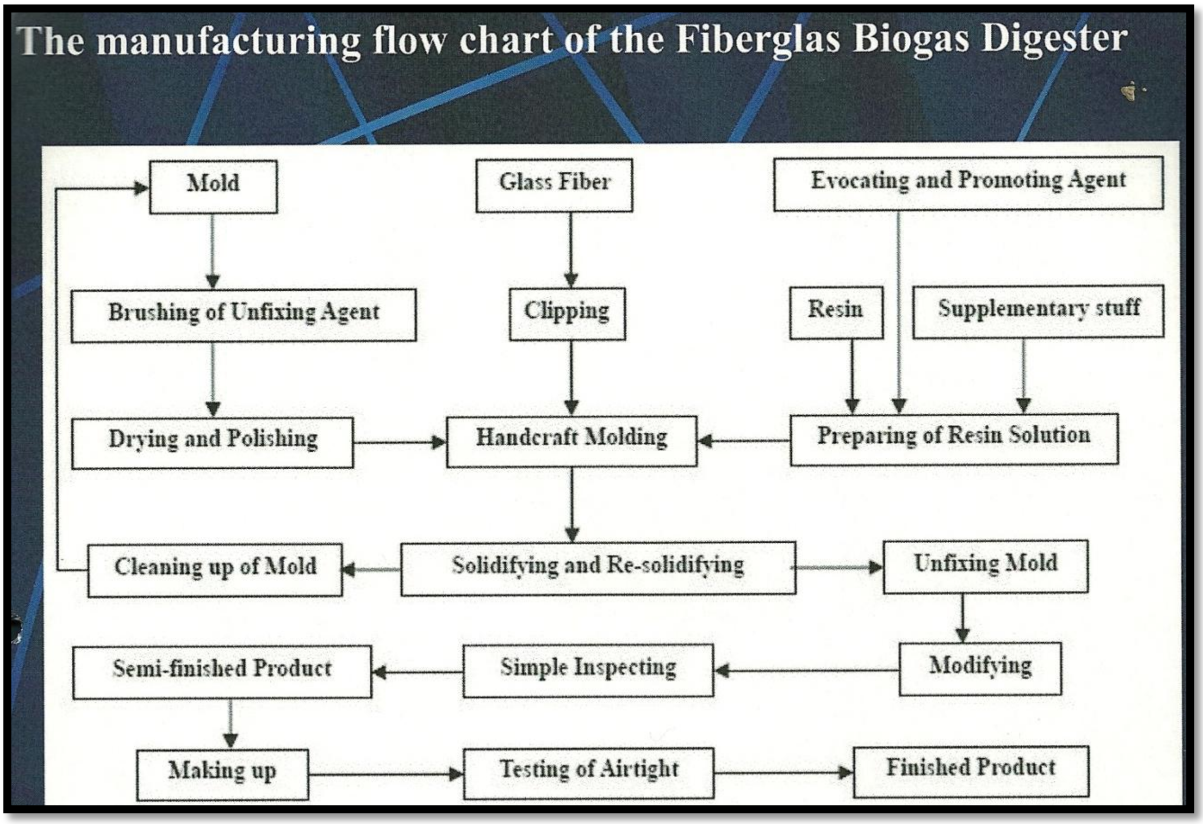

Fig. 13: The manufacturing flow chart of the Chinese fibreglass biogas digester *(NIBIO, 2011).*

According to NIBIO (2011), the fibreglass digesters are characterized by the following:-

- They come in four parts, that is, the inlet, the outlet, the gas chamber and the digester.
- The digester sizes are 4, 6 and 8m^3.
- They are commercially manufactured according to set quality standards.
- They are strong and can withstand pressure.
- They have a lifespan of 20 years.
- They are light in weight .
- They are easier to install and require less labour.
- They are airproof and water tight which ensures that biogas does not escape through leakages.
- Only one skilled worker is required to install the digester as compared to 15 workers for the brick and concrete digesters.
- Installation takes 3-5 hours as compared to 7-10 days for the brick and concrete digesters.

- After installation, the digesters are almost repair and maintenance free.
- If supplied in bulk, the total purchasing and installation costs can reduce to less than a half of the brick and concrete digesters.

The table below shows the key characteristics of the Chinese fibreglass biogas digesters.

Table 5: Key characteristics of the Chinese fibreglass biogas digesters *(NIBIO, 2011).*

Key parameters of $4m^3$~$8m^3$ Digester

Capacity	Biogas space Volume	Diameter of Digester	Max Pressure	Weight of Digester	Livestock	Service Time
$4m^3$	$0.8\ m^3$	2050mm	8.0 Kpa	95kg	3~4 pigs or1cow	20 years
$6m^3$	$1.1\ m^3$	2270mm	11.0 Kpa	120kg	4~6 pigs 1~2cows	20 years
$8m^3$	$1.4\ m^3$	2400mm	11.0 Kpa	145kg	6~8 pigs 2~3cows	20 years

The fibreglass digesters were therefore found to be more convenient in terms of purchasing costs, labour costs, management, strength, being airtight, installation time and service time (lifespan). The digesters have been successfully tested in China, Rwanda, Burundi, Burma and Vietnam (NIBIO, 2011).

The photos below show a complete Chinese fibreglass digester and how they are transported.

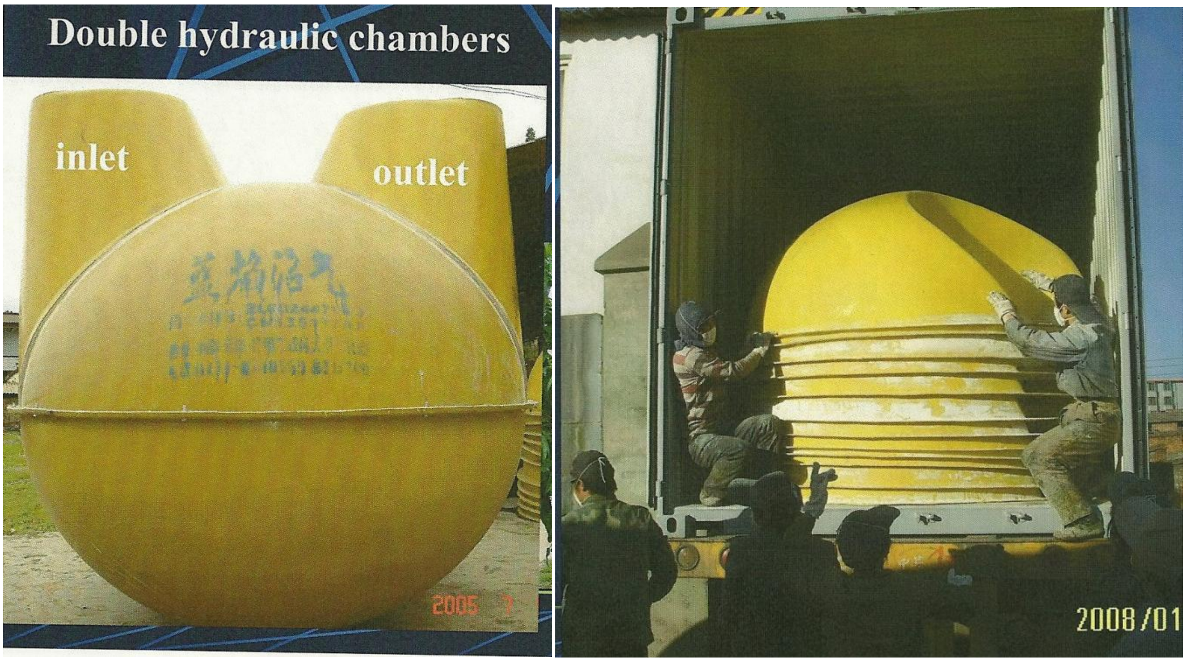

Photo 1: Left: The complete fibreglass digester. Right: They are easy to transport by stacking parts on top of each other *(NIBIO, 2011)*.

3.10 Conclusion

The literature review helped form the basis of this research by giving a summary of what was read about biogas technology. The review provided an overview of the available knowledge from the scholarly secondary sources which have offered previous theoretical, rationale and methodological substantive findings relevant to this research. The literature was mainly sourced from academic-oriented literature in academic journals. While focusing on biogas technology, the literature review included a critical analysis and evaluation of the relationship among different previous studies and the research questions being investigated by this study.

CHAPTER 4

MATERIALS AND METHODS

4.1 Introduction

This section shall give a description of the procedures that were followed in doing this research. This shall ensrure the credibility of the research and that similar results can be reproduced by others. The sub-topics in this section are the study area (contextual background), methodology, activities and data collection methods.

Research method is defined as technique for collecting data involving specific instruments such as a questioner, interview or observation. It involves the research design, sampling approach, access to the respondents, procedures used, nature of questionnaire, interview schedule, observation schedule, coding and analysis (Bryman, 2012).

In addition, research methods should include sufficient details to show that, if a subsequent research is done, similar results shall be obtained. Research methods should also cover a description of the specific actions and activities, the strategy to be used and the steps and procedures to be taken to answer the research questions and accomplish the research objectives. It should also outline the tools used and how. Besides, it is necessary to explain why the methods or methodologies chosen are the best available approaches for the research. This information enables the reader to decide whether the methods used are adequate for the research (Derese, 2011).

4.2 Study area

4.2.1 Kenya

Kenya is one of the countries in East Africa bordering Uganda, Tanzania, South Sudan, Ethiopia, Somalia and the Indian Ocean. It lies on the equator and covers an area of approximately 582,000 km2. Kenya has a warm tropical climate with plenty of sunshine which allows for the agricultural production to be the main economic activity in the country. Temperatures average 22°C throughout the year. The coldest months are from July to August averaging 13°C. The major cash crops in the country are tea, coffee, pyrethrum, wheat and maize. By the last recorded census of 2009, Kenya had a population of 38.6 million, with almost equal number of males and females. Analysts project the population to rise exponentially to 50,319,253 by 2020 and 63,859,547 by 2030. During the same census, 30.9 per cent of the population had completed Primary school while 16.1 percent had completed Secondary school (KNBS, 2012).

The selection of the two study areas in Kenya, that is Kiambu and Embu counties, was based on the fact that these were the areas where biogas technology was vastly promoted by SNV Netherlands and KARI respectively, between 2008 and 2012.

The figure below shows the location of the study areas of Kiambu and Embu counties in Kenya.

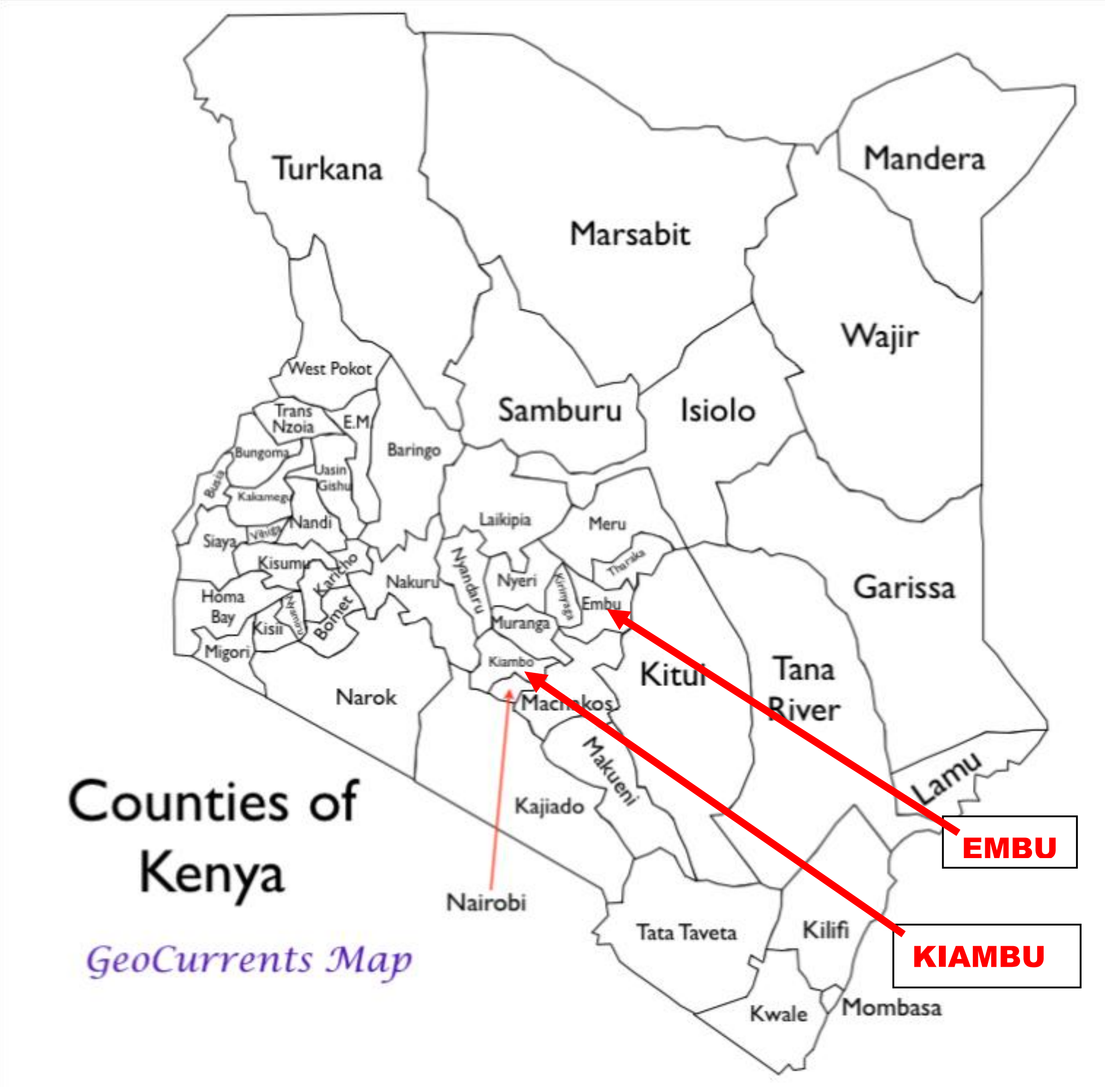

Fig. 14: The map of Kenya showing the study areas *(GeoCurrents, 2016).*

4.2.2 Kiambu County

Kiambu county is located in Central Province of Kenya with a population of 1,602,754. About 40% of the population have secondary level of education or above with 12% population having no formal education. The heating, cooking and lighting sources of energy for the residents in the county are: 13% who use liquefied petroleum gas (LPG), 23% who use paraffin, 35% who use firewood and 26% who use charcoal. Water sources includes ponds, dams, rivers, wells, boreholes, water vendors, piped and rain water (KNBS, 2013). Zero grazing is the most common system of livestock farming, which includes dairy, poultry, pig, goat and sheep (Omiti et al., 2009).

4.2.3 Embu County

Embu county is located in the Eastern Province of Kenya. It has a population of 508,356. Nearly 25% of Embu county residents have a secondary level of education or above but 60% of the population have a primary level of education only. Another 15% of lack formal education. The heating, cooking and lighting sources of energy are: 2% of the population use liquefied petroleum gas (LPG) whereas 4% use paraffin, while 11% use charcoal and the most, that is 81%, use firewood (KNBS, 2014).

4.3 Research Methodology

4.3.1 Introduction (Methods).

This research employed both qualitative and quantitative research methods (mixed research approaches). The qualitative research uses words (descriptive) while the quantitative research uses numbers and measurements (numerical).

Whereas qualitative research brings both the researcher and the subject close to each other, in the quantitative research, involvement with each other is not necessary and can even be done remotely. In addition, qualitative research seeks to understand the meaning of the actions of the subjects whereas quantitative research seeks to understand the behaviour of the subjects (Bryman, 2012).

4.3.2 Qualitative Methodology

The qualitative method was conducted through semi-structured interviews. According to Bryman (2012), qualitative research is aimed at interpreting meanings in terms of finding out what, where, how, who, why and when through the process of inductive reasoning. The semi-structured questions (open-ended) will enable the researcher to have a generalized interview guide (with memory prompts), which can have a varied sequence and at the same time enable the researcher ask additional significant questions.

4.3.3 Quantitative Methodology

Quantitative research helps to clarify meaning through the availability of a choice of answers in form of quantities, which also makes the process easy for both the interviewer and the respondent. The quantitative method was conducted through structured interviews. The structured questions (close-ended) are all standard, specific and with fixed range of answers. Bryman (2012) asserts that, these close-ended questions are exactly the same for all respondents which enable the aggregation of the answers from the survey.

4. 4 Activities/ Format

The importance of a work plan in reserch is that, the plan shows the timelines of the various activities the researcher plans to do and the particular highlights of the research (Derese, 2011). The activities of this study were divided into three phases.

4.4.1 Desk study phase

This phase involved acquiring the necessary secondary data from scholarly sources, preparing the questionnaire, writing and approval of the research proposal, organising for the travel logistics and contacting the key persons and informants in Kenya.

4.4.2 Data collection phase

Empirical data collection in Kenya took 30 days in January 2017. The data, both qualitative and quantitative, were collected from the owners of the biogas digesters and the key informants for the purpose of triangulation. The key informants were the technicians who install biogas digesters and were previously employed by SNV Netherlands and KARI, the official from the Ministry of Agriculture, Livestock and Fisheries, and the official from the KNBS. On average, each interview with biogas owners lasted about 1 hour and 15 minutes, while interviews with key informants took an average of one hour.

4.4.3 Data analysis and thesis writing phase

Upon return to Norway, the raw field and the desk data was evaluated, coded, categorised, verified, assessed and analysed to come up with constructive information. I finally wrote several drafts progressively in preparation for the final thesis.

4.5 Data Collection

4.5.1 Data Collection Overview

The data collected was both primary and secondary. This enabled this study to systematically gather and measure information in order to understand the current and the probable future characteristics of biogas technology systems in rural Kenya.

Data collection is a process through which information is gathered from the sample (respondents) which enables the research questions to be answered (Bryman, 2012). The methods that were used for this research were interviewing using questionnaires, informal discussions and through non-participatory observations. There are two categories of observations, namely participatory and non-participatory. Participatory observations are done while the researcher is an active participant in an event while non-participatory observations are done while the researcher separately observes events or conditions (for example a biogas digester system) (Rowse, 2011). Interviews were either structured (mostly used for quantitative research), or semi-structured (mostly used for qualitative research) (Bryman, 2012).

4.5.2 Primary Data

According to Bryman (2012), primary data is the one that is collected by the researcher themselves. In order to collect this data, people who knew the area well and the development projects therein were requested to organise the interview meetings. I then visited the agreed households at the agreed time for the interviews. I carried out general in-depth interviews on the respondents' experiences, views, history, satisfaction or apprehension of the biogas technology for the qualitative data. The interviews also included closed questions for the purpose of the quantitative data. In-depth interviews were either unstructured, semi-structured interviews or both (Bryman, 2012).

A separate questionnaire was used for the key informants including the biogas technicians selling and promoting biogas technology, the official from the Ministry of Agriculture, Livestock and Fisheries and the official from KNBS. The answers helped in triangulation, which assisted in cross-checking the biogas owner's data. Triangulation should enable "the appearance of the same data from more than one method" (Rowse, 2011) p. 57.

4.5.3 Secondary Data

The secondary data refers to the data that was collected by someone else and not the person doing the research (Bryman, 2012). Such secondary data was aquired from scholarly sources, the KNBS, Non-Governmental Organizations (NGOs), Government ministries and departments promoting biogas including Kenya Agricultural and Livestock Research Organization (KALRO, formerly KARI), Ministry of Agriculture and Fisheries and National Agriculture and Livestock Extension Programme (NALEP).

4.5.4 Data Analysis and Methods

Data analysis is defined as "the management, analysis and interpretation of the data" (Bryman, 2012) p.14. The devise used for audio recording the interviews was a mobile phone recorder. However, this depended on whether the respondents felt comfortable being recorded.

Data collected, including observations made, were transcribed and categorized on daily basis after interviews. Recording is important for qualitative research because it not only presents what the respondent said, but also how it was said. Similarly, recording reminds the researcher things they would otherwise have forgotten. In addition, it enables the researcher to repeatedly examine the answers given by the respondents (Bryman, 2012). The data was coded and thereafter analysed.

4.5.5 Reliability and Validity

Reliability is defined as the consistency of a measure or concept. Reliability involves stability, (that is, whether the measure is stable over time without fluctuation and variation), and internal reliability (which means that the respondent's information is consistent). Validity means that conclusions from a research have integrity and credibility (Bryman, 2012). This research used triangulation method in order to crosscheck and validate the information given by respondents. This would ensure that the data collected is dependable and transferable.

Triangulation is defined as the process of crosschecking findings of quantitative and qualitative research (Bryman, 2012).

4.5.6 Limitations

Although the whole study was expected to be conducted smoothly, there were nevertheless some limitations.

Firstly, the sample size of 176 households was too small. Similarly, only 2 out of 47 counties in Kenya were sampled. The results of this research should therefore be viewed as indicative rather than representative of the whole country. Indeed, the larger the sample size the greater the precision of a research because the sampling error reduces (Bryman, 2012).

Secondly, the information gathered during interviews from the respondents cannot be guaranteed to be 100% trustworthy. Since that is the primary data used to write this thesis, some errors may be expected. Trustworthiness is used to assess the quality of qualitative research (Bryman, 2012).

Thirdly, some of the questions in the interview concerned some sensitive personal information. This includes age, income, land size, education and expenses. There is a probability that the actual information might not have been given. Since personal information cannot be crosschecked, this was therefore a limitation for this study.

Fourthly, there was a limitation of time and finances to conduct this study thoroughly which can lead to errors in the findings. According to Bryman (2012), time and cost is very crucial in determining the precision of a research.

4.5.7 Ethical issues

At the onset of the interviews, I informed the respondents who I am, what research I was doing, why I was doing the research and how I would conduct the research. I informed them what the research will be used for, that is, for my master thesis only. I assured the respondents full confidentiality for them personally and the data they provided. I informed them that their personal information and the data will be held in anonymity and confidentially and shall not be revealed. This information included their identities and their records.

Similarly, I used pseudonyms in the transcripts to ensure that the participants are not identifiable. Before we started the interviews, the participants gave an informed consent and they were entitled to withdraw from participation at any stage without giving reasons and could withdraw the data given too. I also ensured that there was no harm to participants, either real or potential, in terms of physical harm, harming their development, loss of their self esteem and stressing them (Bryman, 2012).

4.5.8 Study tools

The aim of this study was to fulfil the objectives identified above. The information gathered was given more consideration if it had high level of verifiability. The main tool used for this study was the questionnaire (see appendices 1 & 2). By using the questionnaire, structured and semi-structured interviews were conducted for each of the respondents. The other tools used were observations and the informal discussions with the respondents. Apart from the question and answer interviews, an interactive discussion with the respondents helped clarify some of the data given.

4.6 Conclusion

Kenya in general and Kiambu and Embu counties in particular, has an ambient warm tropical climate which is ideal for adoption of the biogas technology. Being an agricultural based economy, Kenya has adequate raw materials necessary for biogas feedstock, which includes manure and biomass.

Both qualitative and quantitative research methods enabled this study to get the appropriate data required to write this thesis. The activities were divided into phases as a guide to the process of completing this study. Both primary and secondary data offered the requisite information for this paper. Triangulation was used to check the reliability and validity of the data from the respondents. Several limitations were encountered although they did not affect the research significantly. Ethics were observed by ensuring the anonymity of the respondents.

CHAPTER 5
SAMPLING METHODOLOGY

5.1 Introduction

Since this field work selected the respondents randomly, simple random sampling method was used. Simple random sampling was an easier and a better procedure in comparison to both stratified and cluster sampling methods in terms of time and finances available. These three sampling methods fall under probability sample method. The former would have involved dividing the whole population into separate groups (strata) and then a probablity sample drawn from each group. The latter would also have involved dividing the whole population into separate groups (clusters) and then a a simple random sample drawn from each group (Bryman, 2012).

Similarly, due to cost and time limitations, the questionnaire had a mix of both qualitative and quantitative questions. However, transcription and sorting of answers was done separately on daily basis during the field work.

Sampling is defined as "the selection of cases which are relevant to the research question (Bryman, 2012) p.14. Sampling of areas and participants is further described as a common strategy of selecting the respondents in a research. Selection methods may be based on the principles of probability sampling or non-probability (purposive) sampling. Probability sampling dictates that the sample is picked randomly with an equal probability of being selected. However, in non-probability sampling, only strategic and relevant samples are selected (Bryman, 2012).

5.2 Sample Size

The sample size for this research was dependent on the time and resources available. The criterion for respondents was those who have installed biogas digesters for a minimum of five years. In each of the two counties, the proposed sample size was 125 respondents whose biogas digesters are either fully or partially working or have completely failed. This brought the proposed total for both counties to 250. However, due to some limitations, the actual sample size for Kiambu county was 94 and for Embu county was 82 bringing the total to 176 as indicated in the table below.

Sample is defined as the microcosm, segment or the subset of a given population which is selected for the purpose of a research (Bryman, 2012).

Table 6: Sample Size (n=176).

County	Proposed number	Actual number	% Sampled
Kiambu	125	94	75%
Embu	125	82	66%
Total	250	176	70%

The table above shows the number of the proposed and actual sample size interviewed. The reasons why not all the proposed respondents were interviewed was because of shortage of time, some respondents did not keep the agreed appointments and therefore were not available for the meetings, and the long distances covered between one respondent to the next especially in Embu where people have huge pieces of land. This research also lacked financial and time capacity to re-visit the same respondents a second time.

A total of 70% of the proposed sample size was achieved thus giving the findings of this study quality in terms of credibility, transferability, dependability and confirmability. Credibility shows how believable findings are, transferability means the findings can apply to other contexts, dependability means that the findings can apply at other times and confirmability means the researcher acts in good faith without allowing personal values to sway the research findings (Bryman, 2012).

5.3 Selection of Respondents

This research used simple random sampling to select respondents. From the registers of all the people who had installed digesters, a sample size of 125 units per county was randomly selected out of the whole population. By using random selection, each of the unit was to be selected by chance thereby giving it an equal probability of being selected. The results of this research will, therefore, generalize the random sample to the whole population in the study areas.

Simple random sampling is the most basic form of probability sampling. Simple random sampling denotes that each of the population unit has an equal chance to be included in the sample, without any human bias. The selection is therefore entirely mechanical. Similarly, simple random sample is not dependent on the availability of respondents for inclusion purposes. This is because, selection of the simple random sample is done without the knowledge of the respondents and it is until they are contacted that they become aware that they are part of the research (Bryman, 2012).

5.4 Digester Types

This research had proposed to focus mainly on two types of digesters which have been the most common in Kenya: the fixed dome and the plastic tubular digesters. These digesters are defined as small by nature, which according to Cheng et al. (2014), are "small-sized biogas systems (SBS) based on a household-scale biogas digesters and are described as integrated systems that include pre-treatment of feedstock, biogas utilization, and post treatment of digestate [... whose volume] should be less than 20 m^3 (p.1373).

In Kiambu county, there was a high concentration of the fixed-dome type of digesters, built of concrete and bricks, which were installed by the SNV Netherlands Development Organisation from 2009 (Ghimire, 2013). The advantages of fixed-dome digesters are that they have no moving parts and they have a long lifespan of 20 years. In Embu county there was a high concentration of the plastic tubular digesters which were also installed from 2009 (Karanja & Kiruiro, 2010). However, this study realised that all the plastic tubular digesters (PTD) installed by Kenya Agricultural Research Institute (KARI) had failed within a year or two. Indeed, the plastic tubular digesters have a short lifetime of two years (Karanja & Kiruiro, 2010). The PTD was installed by first inserting one polythene tube into the other to create a double layer, which increased the strength of the digester. It was then laid horizontally in the trough-like tunnel with the inlet and the outlet on opposite ends. A gas pipe hole was punctured through the two plastic layers about one metre from the inlet end. The digester took about a week to activate, after which the biogas could be used (Karanja & Kiruiro, 2010; Rowse, 2011).

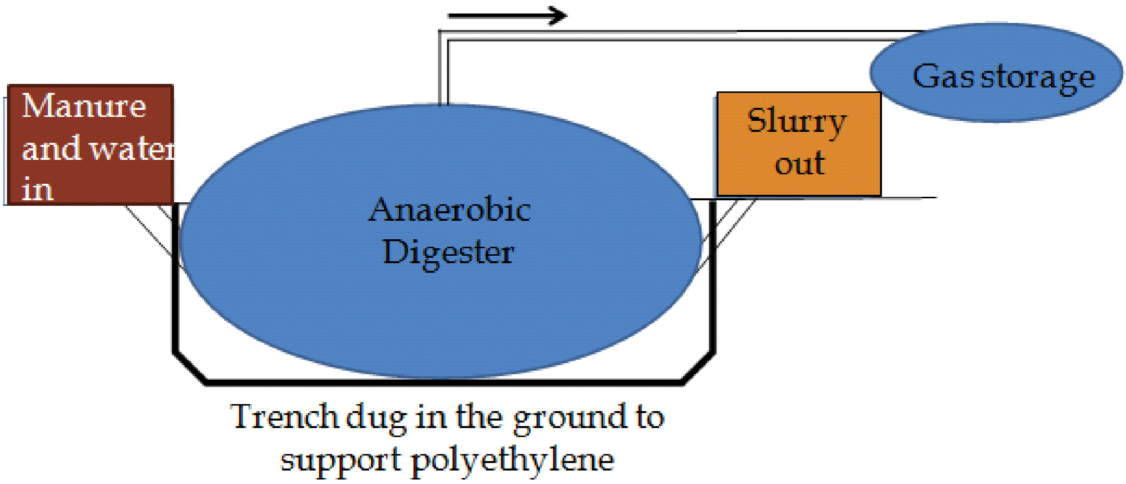

Fig. 15: Polyethylene Tubular Digester. *Rowse (2011)p. 38.*

The respondents who had installed the PTDs in Embu county gave reasons for failure as irregular feeding, substrate mixed with sand and biomass particles, lack of technical assistance, plastic perforated by moles from underground, lack of protection from animals while others didn't know why. Some have since upgraded and installed the fixed dome digesters. These digesters are either made of bricks and concrete or using remodelled plastic water tanks. Therefore, this study changed and put emphasis on the fixed dome digesters only.

5.5 Conclusion

Simple random sampling was used for this study for selecting the respondents thus giving each unit an equal chance of being included. A sample size of 176, equivalent to 70% of the proposed respondents who had installed fixed dome biogas digester systems for over five years were interviewed. This study had proposed to study both the fixed dome digesters and the plastic tubular digesters. However, all the plastic digesters had all failed, and therefore, only the fixed dome digesters were studied.

CHAPTER 6
RESULTS AND DISCUSSIONS

6.1 Introduction.

Biogas use in Kenya has been growing, amid slowly, for the last 60 years since it was introduced. Although this study found out that the biogas systems that were sampled were performing satisfactorily, there is still, nevertheless, room for improvement.

In an interview with the official from the Ministry of Agriculture, Livestock and Fisheries, this study found out that, popularization and promotion of biogas use in Kenya has been low. Such popularization and promotion can lead to further improvements of the functioning of the biogas systems. This research could not find any single government policy document dedicated to biogas in Kenya which therefore indicates that, biogas technology is not taken seriously. The main organisations which were promoting biogas technology (KARI, SNV and GTZ), have since stopped doing so. There are currently only a few scattered small scale business people who are still installing the biogas systems but the lack of promotion of the technology has meant that it has been hard for them to find market for their products. This research found out that there lacks tripartite coordination and collaboration among the main key players in the biogas industry namely the government, the NGOs and the private sector, which can improve the current 0.03% of the technical potential of biogas digester systems installed.

Some of the reasons which hamper widespread adoption of biogas technology in rural Kenya are lack of finances, subsidy, enough feedstock, extension services and technical information (Justus K Laichena & Wafula, 1997). Other challenges are lack of new research information, political and security problems and the failure of biogas projects at the pilot phase (Mulinda et al., 2013).

This chapter shall cover the following sub-topics: demographic, economic and educational status; installation, operation and management of biogas systems; biogas system and functioning; biogas impact on users; financial and economic analysis; and finally, linking biogas with government and private sector initiatives.

6.2 Demographic, Economic and Educational Status of the Households

This study observed that most of the households that had installed biogas systems, by Kenyan rural standards, were well off economically in terms of income, land size, livestock and education. The official from KNBS explained that about 60% of the Kenyan rural population live below the poverty line, earning less than US $1 a day.

About 95% of all people who adopt the fixed dome biogas technology in rural areas are classified as either of medium or high income bracket (Bond & Templeton, 2011).

6.2.1 Population

In total, 176 households were surveyed and average household size was 5.1 persons. The male population was 561 (62%) and the female was 338 (38%) totalling to 899. The following table shows the population distribution showing age and sex in all the households.

Table 7: Households' age and sex distribution.

Age Bracket	Male No.	Female No.	Total No.	% of the Total
Under 15	33	23	56	6.2
15 - 29	79	53	132	14.7
30- 44	307	101	408	45.4
45 - 59	72	79	151	16.8
60 - 74	50	51	101	11.2
0ver 75	20	31	51	5.7
Total	**561 (**62%)	**338** (38%)	**899**	**100**

The combination of the age groups with the highest population was between 30 to 59 years old. They comprise a combined 62% (45.4+ 16.8) of the population. This is therefore the most appropriate age group which should be targeted by those promoting or selling biogas systems.

In addition, this study sought to find out the family members population distribution in the households sampled. The outcome was as per the table below.

Table 8: Family Members Population Distribution in the households

Family Members	Households	% of Households
Under 3	7	4
3 - 5	28	16
6 - 8	57	32
9 - 11	51	29
More than 11	33	19
Total	**176**	**100**

The table shows that families with household members between 6 and 11 are the most common among those who have installed biogas digesters systems, comprising 61% (32+29). Such families, therefore, have the highest potential to install biogas systems.

6.2.2 Main Occupation

In Embu county, most respondents depend on agriculture as their main occupation. Respondents in Kiambu county depended on a combination of agriculture, employment and small-scale businesses. However, in both counties, some were retired workers.

The table below shows the main occupation patterns in both counties.

Table 9: Main occupation patterns of the household head in Kiambu and Embu counties.

Kiambu County			Embu County		
Main Household Occupation	**Total**	**%**	**Main Household Occupation**	**Total**	**%**
Agriculture	4	4.3	Agriculture	54	65.9
Employed (Civil servant)	19	20.2	Employed (Civil servant)	5	6.1
Employed (Private Sector)	8	8.5	Employed (Private Sector)	2	2.4
Employed (Organisation e.g. NGOs)	13	13.8	Employed (Organisation e.g. NGOs)	9	11.0

Self Employed (Business)	44	46.8	Self Employed (Business)	6	7.3
Unemployed	1	1.1	Unemployed	2	2.4
Retired	5	5.3	Retired	4	4.9
Total	**94**	**100**	**Total**	**82**	**100**

The data shows that the main occupation for most biogas owners in Kiambu county was running self-employed businesses (46.8%), while in Embu county, it was agriculture (65.9%). These groups should therefore be targeted for biogas installations.

6.2.3 Land Size

This study found out that majority of the households from Kiambu county had smaller land as compared to those of Embu county.

The table below shows the land holdings in both counties.

Table 10: Land Holdings

Kiambu County			Embu County		
Size (Acres)	**Households**	**%**	**Size (Acres)**	**Households**	**%**
Under 1	23	24.5	Under 1	0	0
1.1 - 2	39	41.5	1.1 - 2	1	1.2
2.1 - 3	18	19.1	2.1 - 3	8	9.8
3.1 - 4	7	7.4	3.1 - 4	12	14.6
4.1 - 5	5	5.3	4.1 - 5	37	45.1
5.1 - 6	2	2.1	5.1 - 6	18	22
6.1 - 7	0	0	6.1 - 7	4	4.9
Over 7	0	0	Over 7	2	2.4
Total	**94**	**100**	**Total**	**82**	**100**

This table indicates that most respondents with the highest biogas installation potential from Kiambu county own one to two acres (42%), whereas those from Embu county own between 4 to 5 acres (45%).

Kenyan rural farmers own an average of five acres of land (Omiti et al., 2009). In addition, Day et al., (1990), also quantifies the average rural landholding in Kenya as two hectares, which is equivalent to five acres.

6.2.4 Livestock Ownership

The average mature cow ownership in Kiambu was 2, while in Embu it was 4 cows. All households sampled had at least one cow. This study was based on cow ownership over the other domestic animals because cow dung is the main digester feedstock in both counties.

The main animal feed in both counties is Napier grass. In Kiambu county, farmers feed their livestock mainly on Napier grass from own farms and buy extra from neighbours. In Embu, the Napier grass is mainly from their farms only and it is enough as they have huge farms. In Kiambu, the feedstock for the digester (substrate) is mainly from cow dung and in some instances, supplemented with chicken, pigs, goats and sheep dung. In Embu the feedstock is mainly from cows only. In Kiambu, farmers primarily practice zero grazing, while in Embu, they mainly practice free grazing as they have bigger farms.

The table below shows the cow ownership figures in both counties.

Table 11: Cow ownership

Kiambu County			**Embu County**		
No. of cows	**Households**	**%**	**No. of cows**	**Households**	**%**
1	24	25.5	1	3	3.7
2	46	48.9	2	6	7.3
3	13	13.8	3	12	14.6
4	6	6.4	4	41	50
5	3	3.2	5	16	19.5
Over 5	2	2.1	Over 5	4	4.9
Total	**94**	**100**	**Total**	**82**	**100**

In Kiambu, most respondents owned up to 2 cows (74%) whereas in Embu most respondents owned between 4 and 5 cows (70%), with 50% owning 4 cows. Famers with such a number of cows have a higher potential of installing biogas than the rest. Forty seven respondents said that they had increased number of cows after installing their digesters in order to increase the cow dung quantities.

Previous research has found that rural farmers in Kenya own less than 20 ruminant animals, which is a combination of cattle, sheep and goats (Omiti et al., 2009). Cow dung is one of the most efficient feedstock to use for producing biogas (Abubakar & Ismail, 2012). In order to meet the daily cooking and lighting needs, a minimum of three cows can provide the required dung quantities (Ghimire, 2013). If the livestock are free-ranging during the day and penned at night, it is assumed that 50% of the manure for use in the feedstock is accumulated in the penned area while 50% remains in the grazing fields. However, for the zero grazing livestock penned throughout the day, manure accumulation for use in the feedstock is 100% (Rowse, 2011).

6.2.5 Education

The table below shows the highest education level attained by the heads of the households interviewed.

Table 12: Highest education level of the household head

Kiambu County			**Embu County**		
Education Level	**No.**	**%**	**Education Level**	**No.**	**%**
No education	2	2.1	No education	9	11.0
Primary	9	9.6	Primary	42	51.2
Secondary	43	45.7	Secondary	21	25.6
College	32	34.0	College	7	8.5
Bachelors	6	6.4	Bachelors	2	2.4
Masters	2	2.1	Masters	1	1.2
Total	**94**	**100**	**Total**	**82**	**100**

The data shows that those with the high potential to install biogas in Kiambu had secondary education, that is, 43 in number, equivalent to 45.7%. In Embu, most had primary education, which is 42 in number, equivalent to 51.2%. In Kiambu, most educated respondents previously used LPG gas because they could afford to buy this energy source using their salaries and business returns. The less educated mainly used firewood previously. However, in Embu, educational levels did not determine biogas ownership because, most respondents with low education, had installed the systems.

According to the KNBS official, in the rural Kenya, 33% of Kenyans have no education, 49% have primary education while 18% have secondary education and above. It can therefore be generalised that, education levels do not necessarily determine the probability of adopting biogas technology in rural Kenya.

Previous research has shown that adoption of new technology is related to higher levels of education (Roubík et al., 2016). The Embu data, therefore, contradicts the theory by Roubík et al. (2016) that, as educational levels rise, so does the adoption of new technology. This theory should, therefore, be considered contextual rather than universal.

6.3 Installation, Operation, and Management of the Biogas Systems

6.3.1 Installation

6.3.1.1 Why Install Biogas Digester

Most of the respondents cited economic benefits as the main motive behind the installation of the biogas digesters. These benefits were derived from the savings of time and money previously used to access and use of the other conventional sources of energy. Others cited health benefit because biogas does not emit smoke which previously caused respiratory diseases. Others installed because of the the promotions and publicity by the organisations installing the digesters, that is, KARI, SNV Netherlands and the private companies. SNV was actively promoting the fixed dome biogas programme in nine African countries including Kenya from 2008 (Ghimire, 2013). Still, others were motivated by friends and relatives who had installed digesters previously.

Other respondents cited the benefits of the slurry as free fertilizer and also reduces the costs of fish feed. In Embu, there were 16 households which were rearing fish in ponds where slurry improved the growth of algae that fish feed on (Food and Agriculture Organization, 1992) . Finally, some argued that biogas brought them prestige and respect in their community. However, just a negligible number of households mentioned environmental benefits as a motivating factor for installing the digesters in both counties.

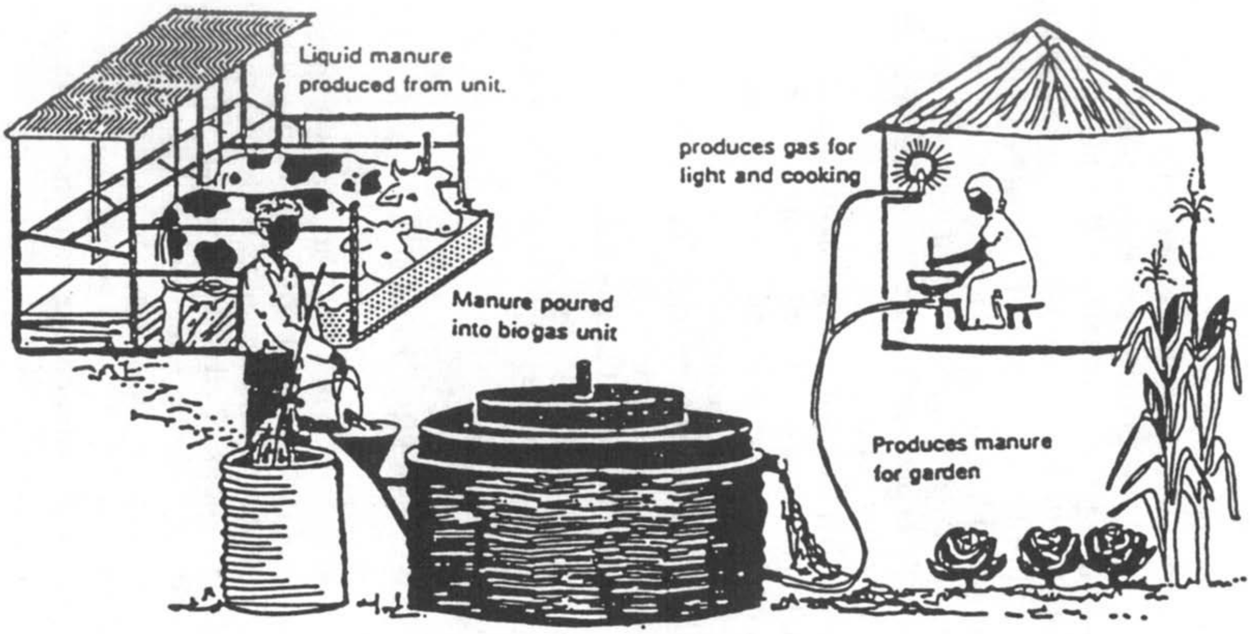

Fig. 16: A schematic zero grazing system and biogas plant *(Day et al., 1990) p. 86.*

6.3.1.2 Digester Sizes

The sizes of the biogas digesters sampled were 4, 6, 8, 10 and12 m^3. According to the technician interviewed, the smallest size, i.e., 4 m^3, produces enough biogas to cook three meals for a family of up to five members.

The respondents with the larger digester sizes than 4 m^3 said that the gas is enough for their daily needs, while those with the smaller ones said the gas was not enough and therefore they had to supplement with other sources of energy including firewood, charcoal and kerosene. Some of the households with the larger digesters also used the biogas to run chaff cutters. The organisations or the technicians promoting biogas are the ones who suggested the digester size depending on the amount of cow dung available. However, in some cases, the digester size was determined by the availability of finances in the household.

A previous study quantified that, biogas digester ranging from 4 m^3 to 15 m^3 produce biogas quantities raging from 1,000 to 3,500 litres per day (Ghimire, 2013). In addition, the size of the biogas digester to install should be determined by the amount of cow dung available which also determines the theoretical gas production (Ullrich, 2008).

6.3.1.3 Digester System Construction and Installation

According to the two technicians interviewed, the initial project digester systems in Kiambu and Embu counties were constructed and installed by technicians trained by SNV Netherlands and KARI, the two organisations promoting biogas in both counties respectively. The technicians had adequate knowledge on biogas system construction and standards. Later on the technicians trained other new technicians at a small fee who then formed small, sole-proprietorship private companies for installing the digesters at a larger scale.

The technicians further explained that the construction and the installation of the biogas system is a very important factor to consider in order to ensure the success of the biogas system (to work best) and to get maximum benefits as shown in cost/benefit analysis. Faulty construction was major problem. There is need to design modern and standard biogas systems and components. Such systems will be able to reduce installation costs and time drastically.

6.3.1.4 Biogas Investment Subsidy and Financing.

According to the technician, KARI did not offer any subsidies in Embu county but rather offered supervision services to the households that upgraded their systems. However, in Kiambu county, SNV offered a flat rate of 20% subsidy to the initial households that installed the digesters. The owners contributed the rest 80%. Nonetheless, the households were supposed to pay for any services needed after the installation of the digester systems.

The total costs of installing a fixed dome biogas digester system was determined by the size, materials required and the labour. According to the respondents, the costs ranged from KSh. 50,000 (US $ 480) for the 4 m^3 size to 90,000 (US $ 860) for the 12 m^3 size.

Some of the respondents (62%) felt that the cost of construction of their respective biogas systems was manageable while the others (38%) felt the cost was too high compared to their own abilities. Those who received subsidies felt that it was a main motivating factor to install the biogas systems.

Research has shown that, the main constraint for rural households to construct a biogas system is the high investment costs required. However, this constraint can be overcome if the government offers subsidies. For example, as a result of the Chinese government offering its citizens two-thirds subsidy of the cost, millions of rural farmers installed biogas digesters (Rajendran et al., 2012).

6.3.2 Biogas System Operation.

According to the respondents, the main task involved in ensuring the entire biogas system is functional is the correct feeding of the digester and the frequency. Other important activities are: unclogging condensed water from the gas pipe using a water trap, cleaning the biogas stoves and lamps, sealing gas leakages including pipe joints and valves, and regularly removing the exhausted slurry from the outlet. The technician explained that, failure to adhere to any or several of these tasks was the main cause of the failure of the digester systems

6.3.2.1 Feeding the Digester

The respondents used either one or combinations of the following raw materials, mixed with water (at the ratio of 50:50):- cow dung, goat and sheep dung, pig dung and chicken droppings. A large number of respondents (66%) said they had adequate feedstock, while others (34%) had to get additional materials from other households. Research shows that livestock manure wastes are 65.6% degradable (Rowse, 2011).

A previous study indicates that, the amount of biogas produced is determined by the correct feeding ratio of the digester. Overfeeding means that the bacteria cannot degrade all the substrate in the digester, while underfeeding means less gas is produced. In addition, if the feedstock is highly concentrated, fermentation is slowed down, while diluted feedstock causes scum formation. The digester should be filled until the feedstock reaches the bottom level of the outlet chamber (Rajendran et al., 2012). Fresh manure produces more gas than the dry manure because organic materials are lost during drying in the open air (Day et al., 1990).

Photo 2: Feedstock preparation. Left: Mixing cow dung with water in a drum. Right: Fresh cow dung in a wheelbarrow. *Photo: (Wamwea, 2010).*

Another finding from previous research indicates that seeding can speed up biogas production. Seeding is done through addition of substrate containing microbes from the digester to fresh feedstock. Comparatively, fresh feedstock alone takes several days to produce biogas while seeded feedstock begins to produce biogas almost immediately. In addition, seeding can be done by adding *talinum triangulare* (water leaf) in the feedstock as a seeding agent. Talinum triangulare is described as a tropical weed which grows throughout the year in the humid tropics (Ebuniloa et al., 2015). Seeding can also be done by obtaining and adding substrate from another functioning biogas digester or from microorganisms found in the dung in the stomachs of freshly slaughtered cattle (Rowse, 2011).

According to the respondents who had the average size digesters, that is $8m^3$, they on average fed a mixture of 30 kilograms dung and 30 litres water, two or three times a week, to produce the maximum biogas. Their assumption was that one kilogram of wet cow dung is equivalent in weight to one litre of water. This research could not confirm this theory. However, research has shown that, for efficient biogas production, feeding the digester requires equal proportions of biomass and water (Rajendran et al., 2012). The minimum required amount for the smallest type of digester ($4\ m^3$), is 20 kg of dung daily (Ghimire, 2013).

The ratio of the raw materials mixed with water should be 50:50 to form the feedstock. However, some digesters sampled were fed at varying ratios: either more water than the dung or the vice versa. This affected the amount of the gas produced. The reason for the varying feedstock volume ratios was because, those households with less cow dung tended to use more water as a compensation and vice versa. On observation, respondents who mixed higher water ratios had slurry that was thin and diluted while those who mixed using more cow dung than water had thick slurry visible from the slurry outlet. The reasons given by respondents for underfeeding were lack of enough dung, not aware of the recommended quantities and workers carelessness.

The respondents said that they reduced the feeding frequency during the cold seasons because the bacteria became less active to digest the cold substrate. They instead collected the slurry from the displacement chamber, added some warm water and fed the mixture back into the digester again. This is similar to the seeding method as described above.

All the respondents said that they removed the solid materials using hands and did not know what percentages of the solid particles were left in the feedstock. Several studied suggest that, fodder residue, sand and stones should be removed from the feedstock (Ullrich, 2008). In addition, unwanted materials should be removed by passing the feedstock using a sieve with a mesh measuring 0.5cm x 0.5cm (Abubakar & Ismail, 2012). For the best biogas production, the amount of solid concentration of the feedstock should not be more than 10% (Rajendran et al., 2012).

6.3.2.2 Other Operational Activities

According to the respondents, other crucial activities to ensure that biogas systems worked effectively were not carried out at any particular time or frequency, but they were done when and if necessary. This happened when the gas reduced at the point of use, especially when the length of the burner flame reduced. Most respondents never bothered to check for leakages in the pipe joints and valves nor did they clean the biogas stoves and lamps. However, almost all respondents drained the condensed water in the gas pipeline using the water trap. At the same time, they removed the exhausted slurry regularly from the outlet and transported it to their farms. The main reason given for not carrying out the necessary activities frequently was because the biogas owners were not trained on maintenance. Other reasons were ignorance and negligence by the workers.

All the sampled households asserted that there were minimal and insignificant operational costs of the biogas system. This was because most of the raw materials, including cow dung and water, were freely available and the labour was done by the family members.

However, even if the labour was to be paid for, most of the respondents said that the costs are negligible. An equivalent cost of the labour calculated in monetary terms was on average KSh. 600 (US$ 5) per month.

Previous studies had similar findings on the negligible operational costs. Operational costs for installed biogas digesters are minimal (Ullrich, 2008). Similarly, after the biogas system has been installed, operation costs incurred are low (Sovacool et al., 2015).

6.3.3 Management of the Biogas Systems

6.3.3.1 Provision of Services to the Users by the Technicians.

Most households in both counties were unanimous in reporting that service provision was not efficient. The technicians, who are the only service providers, did not have offices. There were no written agreements on the after sales services, and therefore the services were not guaranteed. Therefore, the services were not done on time but at the availability and pleasure of the technicians. The technicians were the ones who set the costs of the services which the users felt were high most of the time.

Accordingly, a previous study recommended that, a mutual written agreement between the biogas system contractor and the owner is important ensure rights and responsibilities for both parties (Ullrich, 2008).

6.3.3.2 Training of Biogas Users by the Technicians.

In addition to inefficient services, the respondents raised the issue of lack of adequate training by the technicians on how to operate and maintain their biogas systems. None of the households sampled was given an operational manual but rather were given on spot instructions as the technicians installed the biogas systems. None of the respondents was confident enough that they could carry out basic repairs in case their biogas structural systems failed. Several respondents argued that the technicians refused to train them so that the technicians got job security and monopoly for repair and maintenance.

6.3.3.3 Gas Production and its Usage.

All households used biogas for cooking (100%), 44% used it for both cooking and lighting while 9% used biogas for cooking, lighting and running the chaff cutters. The cooking stoves were either the ordinary gas cookers modified to use biogas or locally assembled burners.

The respondents explained that biogas was mainly used to cook light foods. For food that required longer cooking hours (e.g. "githeri", a mixture of dry maize and dry beans which requires minimum four hours continuous boiling time) most households used firewood or charcoal as the biogas produced was not sufficient. According to the technician interviewed, the insufficiency of the biogas was as a result of incorrect feeding of the digester, defects in the biogas structural systems or gas leakages. He further explained that, biogas from an efficient medium size digester ($8m^3$) should burn for five hours continuously.

6.4 Biogas System and Functioning

In order to understand how the entire biogas system can function properly, it was necessary to understand how the components function, the benefits derived from biogas, the owners' feelings and expectations and their satisfaction levels.

6.4.1 Biogas Digester System Components

Most the biogas systems sampled in both counties had similar design and components, apart from the plastic tank digesters in Embu county. This means that the technicians in both counties were likely to have been trained using similar materials and methods by both KARI and SNV Netherlands. All the necessary biogas system materials and components were available locally or in hardware shops in the nearby towns.

6.4.1.1 The Biogas Digester and the Gas Storage Dome.

Two types of digesters were sampled. All the digesters in Kiambu county were fixed domes constructed using bricks and concrete. In Embu county, 70% digesters were similar to those of Kiambu county. The remaining 30% were made of prefabricated plastic tanks. According to the technician, the plastic tank digesters were the more recent to installations (2011 to 2012). Previous research shows that, more recent designs of digesters have higher performance and functionality than the older designs (Bond & Templeton, 2011).

Digesters made of bricks and concrete took longer time to construct whereas the plastic tank digesters took less time and labour because they came prefabricated.

Photo 3: The Biogas digesters. Left: Brick and concrete digester buried in the ground. Right: Prefabricated plastic digester buried halfway in the ground. *Photo: (Wamwea, 2010).*

It was not possible to ascertain the workmanship quality of the brick and concrete digesters because they are fully buried in the ground with compacted soil. Rather, this study relied on the answers given by the respondents, the technicians, and to a lesser extent, through observations.

Whereas the brick and concrete digesters were spherical in shape, the plastic ones were cylindrical with same size circular ends, lying on the side. The spherical shape of the digester ensures high degree of structural stability (Justus K Laichena & Wafula, 1997).

The plastic tank digesters are buried halfway in the ground. A previous study show that, the reasons why the digesters are buried in the ground are to insulate them when it gets cold and to maintain a constant temperature of the substrate inside the digester. It is the geothermal temperature that helps maintain the substrate temperature in the digester (Rajendran et al., 2012).

The technicians further explained that, the other reasons for building the digesters underground were to protect them, to stabilize them, and in the case of brick and concrete digesters, to avoid inundation when it rains. The circular plastic digesters can also roll over if they are not stabilized.

According to the technician, the brick and concrete digesters are constructed by using a mixture of sand and cement to attach the bricks. The ideal sand and cement mixture ratio is 2:1. The lower part of the digester is where the feedstock (or substrate) fed in the digester settles. The upper part which is shaped as a dome is where the gas that is produced is stored ready to be transported for use for cooking, lighting and other activities.

After construction, the entire digester, both inside and outside, is plastered using cement paste to ensure that it is compact, waterproof and airtight (finishing) so that the gas cannot escape. The digester is not made air tight not only stop gas from escaping, but also to keep oxygen from entering the digester, which can affect anaerobic digestion. Sealing for air tightness can also be done using polymer paint on the inside of the digester, which is also used to water-proof water storage tanks (Rowse, 2011).

Curing of the digester takes two weeks on average. To ensure the digester becomes strong, it should be watered twice a day, in the morning and the evening. The interior walls are scratched to make them rough so that the bacteria used to digest the substrate can hold on to them. The technician explained that this is different from the plastic digester which has smooth interior and therefore bacteria are flushed out with the slurry thus reduceing the amount of gas production.

Research shows that active bacteria cling to digester surfaces, and the more the surface area, the more the bacteria population. Making the walls rough can be an alternative to using a fixed film. A fixed film is formed when a media (intermediate layer) is immersed in the substrate whereby bacteria attach to the media thus forming a film that prevents the bacteria from being flushed out with the slurry (Wilkie, 1998).

A study on biogas digester construction has shown that, to ensure that the biogas digester is of good standard, construction materials should be of good quality. The cement paste is important because it fills up all spaces and as the concrete hardens, cracks do not form. River sand should be used because it has fewer impurities than the overland sand. Bricks should be soaked in water before use and should have a uniform shape. To mix the concrete correctly, cement, sand and ballast should be mixed at the ratio of 1:3:5 respectively. For the concrete to be of the maximum strength, curing should be at least 21 days, while watering it every morning and evening to maintain the moisture level. The wall thickness should be a minimum of 15 cm. Plastering should be done both inside and outside of the digester using a water proof compound to make it gas tight (Ullrich, 2008).

The plastic tank digester comes prefabricated and therefore less time and labour is needed as compared to the constructed digester. The functioning of both digesters is similar. However, because the plastic digesters are not fully buried, less gas is produced during the cold season prompting the owners to add molasses in the digester to increase gas production.

Several studies have found that, due to its chemical properties, molasses is used for co-digestion to increase methane production. Molasses is a bi-product after bio-ethanol extraction industrially (Sarker & Møller, 2013). Molasses is also a bi-product of sugar extraction which contains up to 48% sugar (Fang, Boe, & Angelidaki, 2011). Co-digestion is the process by which multiple organic waste feed stocks are simultaneously digested anaerobically to produce biogas (Fang et al., 2011). Biogas burns best when the methane (CH_4) content is 70% or above (Karanja & Kiruiro, 2010). Molasses is used as a substrate for co-digestion which boosts biogas production after injection (Sarker & Møller, 2013). Molasses increases the production of CH_4 (Clemens et al., 2006). Besides, molasses contains up to 48% sugar, and in addition to being used for industrial fermentation, fertilizer and animal feed, it is also used for co-digestion with animal manure to increase biogas production. In reality, the synergistic effect of co-digestion increases biogas production than mono-substrate digestion, improves the nutrient balance in the substrate and maintains the pH level (Rajendran et al., 2012).

According to the technician, some biogas owners added charcoal to the feedstock to improve gas production. Research has shown that by adding 5% charcoal to cow dung, biogas production increases by up to 34% due to the stimulation of the microbial activity (Kumar et al., 1987).

After biogas has been produced in the digester, it is stored in the upper dome. The biogas is stored in the gas holder until it is consumed (Justus K Laichena & Wafula, 1997). The hydraulic retention time (HRT) of the substrate before it is exhausted in the digester should be between 10-15 days(Rajendran et al., 2012).

6.4.1.2 Feeding Inlet

This study observed that, the common devise used for mixing raw materials (e.g. cow dung) with water, is a drum 1.25m high and 0.5m diameter (see photo 2). A stick is used for mixing until the mixture becomes viscous. A 30 cm diameter circular inlet tank, which is made of bricks and concrete, is where the mixture is fed into the digester, flowing through an inlet pipe, 15cm in diameter and about 1.5 meter long, made of concrete, and at a slightly slanting angle. However, previous research shows that, an alternative of mixing the feedstock in a drum is by connecting the cow stable with the digester. This will ensure that dung and urine will flow by gravity directly into the inlet tank, thus reducing the workload (Ullrich, 2008).

Photo 4: The inlet tank. *Photo: Stephen Ngugi Wamwea.*

A noticeable shortcoming of the inlet was that, should the inlet pipe be blocked, it would be hard to unblock it using a straight stick or a rod as it will need to be bent to manoeuvre the angle of entry. However, such blockage was rare because most of the inlets were sealed using a wedge when not in use to prevent small animals entering the inlet pipe.

According to the technician, the inlet pipe should be constructed in a way that a pole or a straight rod can easily be inserted to mix the contents in the digester in case of clogging which stops the biogas moving up the gas chamber but instead discharged through the outlet into the slurry pit. In the current situation, should there be clogging, the whole digester has to be emptied first, from the outlet side, in order to remove the scum.

Another noticeable shortcoming in 16 of all the 176 biogas systems sampled was the angle of the outlet relative to that of the inlet. According to the technician, the two should be on both the extreme opposite ends to ensure that the feedstock is fully digested to exhaust all the biogas before being discharged out of the digester. However, 16 systems had the outlets placed at an angle closer to the inlets. This was because of where the owners preferred the slurry to come out of the digester from. In essence, the closer distance between the inlet and the outlet at an angle meant that, the hydraulic retention time (HRT) of the substrate was a shorter period, without having released all the gas. This was visible because the slurry in the outlet pit released gas bubbles. Short HRT would therefore reduce the amount of gas produced and leading to inefficiency.

6.4.1.3 The Gas Piping from the Digester to the Point of Use.

The biogas that is stored in the gas chamber is supplied to the point of use through plastic pipes. According to the technician, for an average digester of 8 m^3, a 1" diameter, 40cm long metal pipe, is attached vertically through a hole drilled in the uppermost centre point of the dome. Approximately 20cm goes into the dome while the rest 20cm rises above the dome. The metal pipe is then connected horizontally to a five meter plastic pipe. A gate valve which controls the flow of the gas is also connected to the pipe about five meters from the digester. All the sampled households left this valve permanently open.

Additional similar five meter long plastic pipes are joined together up to the point of use. However, the diameter reduces from 1" to 3/4" then to 1/2" and finally to 1/4" at the point of use. This reduction in diameter increases the biogas pressure as it flows towards the point of use.

Photo 5: Laying the pipes in the trench. *Photo: (Wamwea, 2010).*

Previous studies demonstrate that, the slurry in the outlet chamber exerts pressure in the digester, thereby pushing the gas upwards the dome to the piping system (Justus K Laichena & Wafula, 1997). This gas pressure is created because of the difference of the level of the slurry inside the digester and in the outlet chamber. As soon as the gas is released from the dome, the slurry in the outlet chamber flows back into the digester, thus creating new pressure (Rajendran et al., 2012).

The pipes are buried in a trench. The distance from the digester to the point of use varied in the different households sampled from approximately 10 meters to 80 meters. However, a previous study explains that, the distance to the point of use, for example kitchen, is insignificant, as there is no limit to the length the gas can be transported, except for the cost of the pipes and labour (Ullrich, 2008). To avoid rupturing and gas leakage, flexible pipes should not be used, but rather, texture reinforced pipes. The maximum bending angle of the pipes should not be more than 45°. In order to test pipe leakage, soap foam should be distributed around the joints while there is gas pressure. Such leakage would be visible through bubbling foam and should be sealed (Ullrich, 2008).

The most noticeable shortcoming was that the metal pipe and some part of plastic pipe on the dome were protruding and therefore not protected thus being at the risk of being damaged by humans and animals. These parts were also exposed to sunlight which can lead to the damage of the plastic pipe as it hardens leading to cracking and therefore leakage. Most of the metal pipes were not painted which could lead to corrosion.

When biogas is to be used in the house for cooking and lighting, this study observed that, the gas pipeline then enters the house, mainly the kitchen, through a hole drilled in the wall. A second gas valve is attached to the pipe in the kitchen. This is opened only when the gas is being used directly from the pipeline. A flexible pipe is then connected between the textured pipe and the cooking stove or the lamp.

6.4.1.4 Biogas Storage and Transportation

Most respondents did not have storage facilities for the excess biogas produced. Only 19 of the 176 households sampled in both counties had fixed a gas storage cylinder. These cylinders were the ordinary LPG gas cylinders with some modifications done to function with biogas. The rest of the households piped the gas directly to the point of use. This forced them to burn the gas into the air when the dome became full. However, the technician explained that, biogas can be stored in gas cylinders or gas bags.

Photo 6: An ordinary LPG gas cylinder modified to store the excess biogas. *Photo (Wamwea, 2010).*

A previous study has recommended that, small size biogas systems can store and transport biogas by filling the gas in vehicle tyre inner tubes or other small plastic reservoirs (Rowse, 2011). In advanced countries like Norway, excess biogas is stored and transported in airtight containers as shown in the photo below.

Photo 7: Biogas storage in an airtight container which can be transported, in Lindum Waste Facility, Drammen, Norway. *Picture: Stephen Ngugi Wamwea.*

A previous study recommended that it is important to store excess biogas for use when the pressure is low (Rajendran et al., 2012).

6.4.1.5 Water Trap

This study found out that, further up the pipeline, there is a "water trap" bottle which collects the condensed water from the pipeline at a sloping angle. According to the technician, two of the sampled systems failed due to lack of the water trap. When the gas pipeline is too long without a water trap, humidity in the biogas being transported is condensed into water in the pipeline.

Photo 8: A water trap using an ordinary bottle. *Photo (Wamwea, 2010).*

Research has demonstrated that, if this condensation is not removed, the piping system gets blocked by the water, therefore reducing, or stopping, the biogas delivery to the point of use (Cheng et al., 2014). However, sometimes the water trap is not necessary if the piping system has a straight slope from the digester to the point of use, because any water that is condensed, drains right back into the digester (Ullrich, 2008).

6.4.1.6 The Outlet displacement Chamber and the Overflow Outlet

It was observed that, the slurry leaves the digester by passing through the rectangular outlet displacement chamber then through the overflow outlet opening and finally entering a slurry pit, dug lower than the inlet, so that the exhausted slurry can flow by gravity out to the pit. Some of the slurry pits were not covered and therefore pose a risk of animals and children accidentally falling into the pits and drown.

The technician explained that, the outlet should be covered, for example, using corrugated iron sheets to prevent rain water from entering into the digester and also prevent animals and children from falling into the digester. A previous study elucidates that, should the rain water enter the digester through the outlet, it will increase the water ratio in the substrate, thus reducing the gas production. The outlet system must have walls to prevent inundation when it rains (Ullrich, 2008).

Photo 9: The fixed dome biogas system showing the inlet, the digester and the slurry outlet. *Photo: Stephen Ngugi Wamwea.*

According to the respondents and technicians, whereas the inlet is solely used to feed the digester, the outlet has other four functions. Previous studies and observations were used for triangulation purposes. These functions are:

i. Used as an entry and an exit by the technicians constructing the digester.
ii. During repairs or cleaning of the digester, all the slurry is emptied from the outlet.
iii. As the slurry stagnates during retention in the digester, floccules or scum forms at the top of the slurry and are stirred from the outlet using a stick or a rod. This corroborated with previous studies which found out that, biogas is prevented from rising from the digester to the dome by the thick scum layer (Cheng et al., 2014). Consequently, the substrate in the digester should be stirred regularly (Justus K Laichena & Wafula, 1997). However, it should be noted that, excessive stirring stresses microorganisms, while less stirring leads to foaming (Rajendran et al., 2012). Similarly, the substrate in the digester should be replaced twice a year. Additionally, for efficient biogas generation, the substrate in the digester should be constantly stirred several times daily, in order to mix the substrate (Ebuniloa et al., 2015).

iv. When the quantity of gas increases in the gas chamber, slurry is pushed out through the outlet and when the gas quantity reduces, slurry flows back from the outlet. This ensures pressure is maintained to push the gas up the dome (Rowse, 2011).

6.4.1.7 Cooking Stoves

Two types of cooking stoves were observed. The first type was locally made by the wielders. It is a metal frame burner with a metal pipe extension which is connected to the flexible plastic gas pipe. Gas entering the burner is controlled using a knob connected to the pipe. Most of the households had two-flame burners which enabled them to cook two different pots at the same time. Respondents using this type of a burner said that, on average, it costs KSh. 500 (US $5) and thus affordable.

The other type of stove is the conventional gas cooker, modified to use biogas. Most of the respondents using this type of the burner were previously using the LPG gas. The LPG gas cylinder is also modified to be used as biogas storage devise.

Photo 10: Biogas burners. Left: A locally made metal frame burner. Right: Ordinary gas cooker modified to use biogas. *Photo:(Wamwea, 2010).*

The main problems observed with the stoves were corrosion, rust and clogged burner holes. Respondents could not clarify why these problems occur or the necessary solutions. In addition, respondents regularly observed the colour of the flame fluctuating between yellow and blue, although they could not explain the reasons why.

Previous studies found that, when the gas pressure becomes low, the flame turns yellow. The normal frame is supposed to be a bluish flame. Indeed, methane when combusted, produces a blue flame (Rajendran et al., 2012). The yellow frame is an indicator that enough biogas has not been produced, whereas the blue flame indicates enough biogas has been produced (Ebuniloa et al., 2015). In addition, as the flame gets hotter, the colour changes smoothly from yellow to blue (Bakar et al., 2015).

Using the biogas to cook has quadruple advantages, namely, reduced firewood use, reduced carbon-black smoke, reduced GHGs emissions and improved health in the kitchen (Cheng et al., 2014). According to the technician interviewed, and referring to the training from SNV Netherlands, the traditional three-stone fires using firewood and cook stoves using charcoal have a thermal efficiency of between eight to ten percent. Previous research has demonstrated that, when the biogas system is fully functional, the heat efficiency from the biogas stove is 57%. This is the highest efficiency compared to LPG (54%), kerosene (50%) and wood (23%) (Rajendran et al., 2012).

6.4.1.8 Biogas Lamps

Biogas lamps observed were either the ordinary pressure lanterns or an overhead lamp with a wick made of soft threads as the source of light and modified to use biogas. Light is attained when a small amount of kerosene is vaporised and delivered to the wick which is then ignited and continues to burn using biogas only. The light is controlled by adjusting the amount of gas supplied into the lamp using a knob. Previously, gas for the pressure lanterns was pumped manually into the lamp reservoir but currently, biogas just flow in thus saving time and energy. The technician explained that the optimum light produced by the biogas lamp is equivalent up to a 75 watt light bulb. Similar problems to those of the burners were observed. They were mainly corrosion, rust and clogging of the lamps.

Photo 11: Biogas lamps. Left: The ordinary pressure lanterns. Right: An overhead lamp. *Photo: (Wamwea, 2010).*

According to Rajendran et al., (2012), a biogas lamp produces light equivalent to electric bulbs in the range of 25-75 W. In addition, a biogas lamp illuminates a room better than a pressure kerosene lamp and produces light equivalent to electric bulbs in the range of 25-75 W (Justus K Laichena & Wafula, 1997).

6.4.1.9 Desulphurizer

According to the technician, high concentration of hydrogen sulphide (H_2S) in the biogas is one of the main problems for the biogas systems in Kenya. A desulphurizer is used to remove the hydrogen sulphide from biogas. Desulphurization is also necessary for health, safety and environment. Only 37 of the 176 sampled digester systems used the desulphurizer hence the corrosion, rust and clogging of the gas pipes, stoves, lamps and chaff cutters. All the 37 systems had a similar desulphurizer imported from China. The desulphurizer also has a gauge, called a manometer, which functions as a measurement to show the pressure of gas in digester. The manometer also helps to show when it is necessary to feed the digester when the gas pressure level is low.

Photo 12: The biogas desulphurizer showing the manometer gauge. *Photo Stephen Ngugi Wamwea.*

A previous study explains that, desulphurization is the process where hydrogen sulphide (H_2S) is removed or filtered or scrubbed from biogas. Hydrogen sulphide is formed during the anaerobic digestion of proteins in the digester. Sulphur dioxide (SO_2) is formed when unfiltered biogas is combusted. When biogas containing hydrogen sulphide is combusted, sulphur dioxide is produced. It is this sulphur dioxide that leads to corrosion (Baspinar et al., 2011).

More recent research has found that, hydrogen sulphide (H_2S) in biogas causes wear and tear in internal combustion engines and equipments during combustion when hydrogen sulphide (H_2S) reacts and forms sulphur dioxide (SO_2) and water (H_2O) which further reacts to form sulphurous acid (H_2SO_3) which leads to the corrosion of the internal parts of engines and equipments during combustion (Sankarlal, 2015).

Health wise, research shows that, high concentrations of hydrogen sulphide and sulphur dioxide can lead to vomiting, headaches, nausea, dizziness, blurry vision and chocking (Rajendran et al., 2012).

6.4.1.10 The Chaff Cutter.

The chaff cutters sampled were modified to use biogas instead of petrol or diesel. Only 16 households used the biogas for the chaff cutter. According to the technician, only a small amount of petrol or diesel is used to ignite the machine and once running, biogas is switched on. This saves the cost of fuel because, for example, if a farmer used one litre of petrol per day, the same can last for about two months when using biogas. It was observed in the local petrol stations that a litre of petrol cost KSh. 110 per litre. Therefore, such a farmer can save KSh. 6,600 every two months (110x60) resulting to KSh. 39,600 annually (US$ 377). A biogas pipe is connected to the carburettor. The carburettor is where biogas mixes with air and ignited to drive an engine by internal combustion. A knob is used to control the biogas entering the carburettor of the chaff cutter which also adjusts the speed of the machine, thus the more the biogas, the faster the speed. The technician further explained that, less biogas is used when the fodder is fresh and soft whereas more biogas is used to chop hard and dry fodder.

Photo 13: A biogas chaff cutter. *Photo: Stephen Ngugi Wamwea*

Scientific studies show that, combustion converts biogas into electrical or mechanical energy which runs the chaff cutter (Rajendran et al., 2012). Biogas can also be fed to a generator to produce electricity which is used to ran a chaff cutter (Goud et al., 2016).

6.4.2 The Biogas System Functioning, Operation and Efficiency.

This study categorized the functioning of the biogas digester systems into three: fully functioning, partially functioning and defunct. Of all the 176 biogas digester systems sampled, 72 % were fully functioning, 25 % were partially functioning and 3% were defunct as indicated in the table below.

Table 13: Functioning conditions of the biogas digester systems sampled

Condition	No. systems	%
Fully functioning	126	72
Partially functioning	44	25
Defunct	6	3
Total	**176**	**100**

Of the six defunct biogas digester systems, one stopped working after three years, three stopped working after four years and two stopped working after five years since installation. Four were in Embu county and two were in Kiambu county. None of the six has been repaired yet but the owners said that they are keen to repair them when they can afford to. Of the 170 fully functioning and partially functioning biogas systems, 118 of them equivalent to 69% have been either repaired or cleaned one time or more when they stopped functioning or partially functioned. The fact that only 3% were defunct indicates that there is a high success rate of the biogas systems if the required operational guidelines are followed.

In order to better understand the actual efficiency of the sampled biogas digester systems, it was necessary to make calculations to compare the maximum cooking hours and the expected cooking hours per day. The calculations are only based on gas burning hours.

Out of the 176 sampled biogas systems, 120 of them were the standard size of $8m^3$ in size and are therefore used for the purpose of the calculations below. According to the technician, the gas produced by a biogas digester this size can continuously burn for a maximum five hours.

The table below shows the actual burning hours reported by biogas owners with this size digester and the expected burning hours according to the technician.

Table 14: Biogas system efficiency by comparing actual and expected burning hours.

1	2	3	4	5	6
No of $8m^3$ digesters sampled	Actual burning hrs. per day	Total actual burning hrs. per day	Expected burning hrs. per day	Total expected burning hrs. per day	Efficiency %
82	3	246	5	410	60
29	4	116	5	145	80
9	5	45	5	45	100
120		402		120X5 = 600	67% efficiency

The first column shows the number of $8m^3$ systems sampled. The second column shows the reported number of maximum burning hours per day. The third column shows the total actual burning hours. This is achieved by multiplying the digesters in column 1 and the burning hours in column 2. The fourth column shows the maximum burning hours which is 5 hours nonstop. The fifth column shows the total of the expected burning hours per day by multiplying column 1 and 4. Percentage efficiency in column 6 is achieved by dividing figures in column 5 with those in column 3 and multiplied by 100. The average efficiency for all the 120 digester systems works out to 67%. Only 9 out of 120 of the digesters were 100% efficient.

The reasons given by the respondents on what they believed made their biogas digester systems inefficient or why they failed were as follows, starting from the most common to the least.

Table 15: Inefficiency and failure reasons for the biogas systems by the users.

Inefficiency and failure reasons	Households	%
Lack of repair and maintenance (costly or technicians not available)	47	42
Lack of training	27	24
Didn't know the reasons why	18	16
Not cleaning the system regularly when gas production reduced	8	7
Not filtering large particles in the feedstock	5	5
Workers negligence for example not feeding correctly (quantity,	3	3

quality and ratio) and the feeding frequency, overfeeding and underfeeding		
Poor construction	2	2
Poor quality materials	1	1
Total	**111**	**100**

The table above indicates that the three major reasons why the systems were either inefficient or had completely failed were lack of repair and maintenance, lack of training, and being unaware of the reasons why.

The two technicians removed cited technical reasons as the main causes of inefficiency and failure of the biogas systems in Kenya. One of the reasons given was the unequal water and dung ratio of the feedstock which reduces the amount of gas produced. Another reason was when the substrate in the digester was not fully exhausted before exiting the digester. This was observed in some of the digesters sampled whereby, bubbles are visible in the slurry. They also claimed that cracks can also form in the dome and the piping system, resulting in the escaping of biogas. The other reason was leaking valves and clogged burner holes. Finally, lack of regular stirring of the slurry to remove floccules also caused the inefficiency and failure of the systems.

The failure of a biogas digester system occurs when less than half of daily optimum biogas production is observed (Cheng et al., 2014). Such failure is as a result lack of maintenance and repair of the biogas system (Bond & Templeton, 2011). According to Cheng et al., (2014), faults occur in five subsystems of the biogas system.
These are:-

- Structural components
- Biogas utilization equipment
- Piping system
- Biogas production
- Effluent disposal system.

Other studies show that, as the biogas digester system ages, so is the increment of frequent leakages and failure occurrences (Cheng et al., 2014). System failure can also occur due to scum build-up in the digester, corrosion of the equipments and insufficient knowledge on operation and maintenance by the users. In addition, inefficiency and failure can be caused by low quality construction, pipeline leakages, low biogas production and lack of maintenance (Justus K Laichena & Wafula, 1997) . Further emphasis on why the biogas owners don't follow the recommended practices are insufficient training, lack of availability of maintenance services, gas leakage and low pressure (Amjid et al., 2011). In order to reduce inefficiency and failure of the biogas digester systems, there is a need to educate owners on operation and maintenance of the systems (Justus K Laichena & Wafula, 1997). Besides, spare parts for repairing faults should be easily available in rural areas so that repair and maintenance can be carried out adequately and within the shortest time possible (Rowse, 2011).

6.4.2.1 Temperature

None of the 176 owners of the biogas systems sampled monitored the temperature in their biogas digesters due to lack of awareness. Digester temperature could therefore be considered as one of the factors that led to the inefficiency of the 111 biogas systems.

6.4.2.2 p.H.

None of the owners of the digester systems sampled measured the pH levels of the substrate in their digesters. According to the technician, higher acidity or alkalinity kills the bacteria in the digester. He further clarified that, if the pH levels go higher or lower than the optimal value by 0.5, biogas production can cease. It is therefore necessary that the optimal pH levels of 6.5-7.5 are maintained to ensure continuous biogas production.

The technician explained that, an ordinary pH scale ranges from 0 to 14. Solutions pH less than 7.0 are acidic while solutions with a pH greater than 7.0 are alkaline and solutions with 7.0 are neutral. He further described that measuring the pH in a fixed dome digester should be done by attaching a litmus paper with a stick or a rod and drop it into the substrate in the digester for about five minutes and then remove it and compare the colour of the litmus paper with the standard chart of pH colours to determine the pH level in the substrate. However, as a shortcoming, none of the digesters sampled had a design provision for dropping the stick into the substrate. He added that, a yellow biogas flame is an indicator that the substrate is acidic and that lime or ash should be added in the substrate to adjust it to the optimum pH and then the flame colour shall change to blue. In addition, if such yellow flame is observed, only cow dung should be used as the feedstock, without mixing with other raw materials in order to adjust the pH levels.

An earlier study shows that, a litmus paper is one of the instruments used to measure the pH levels. The value 7 of the litmus paper is the neutral level. Lower values than 7 indicate increasing acidity whereas higher values than 7 indicate increasing alkalinity. The pH determines the stability of the substrate in the biogas digester (Bouallagui et al., 2003).

The bacteria that produce biogas are sensitive to the acidic low pH levels substrate. When the pH levels get lower than optimal values, biogas yield is lowered and can even cease completely. However, by using cow manure only, pH level buffering capacity is increased because cow manure has a typical pH of 7.4 which is within the optimal level (Labatut & Gooch, 2012). Similarly, the anaerobic bacteria in the cow dung effectively degrades the organic matter in the dung irrespective of whether the pH is regulated or not (Abubakar & Ismail, 2012). In addition, suitability of cow dung as the ideal substrate is because the stomachs of ruminant animals have methanogenic bacteria (Bond & Templeton, 2011). Use of cow dung, therefore, could be the probable reasons why most of the biogas systems sampled were still functioning, although pH was not regulated.

6.5 Biogas Users' Perceptions and Impacts

6.5.1 Perception on Satisfaction of the Biogas Digester System and Usage

The respondents were asked their satisfaction levels with the general output and functioning of their biogas system and given three options to choose from: fully satisfied, partially satisfied or not satisfied.

The table below shows the satisfaction levels of the respondents.

Table 16: Perceptions on satisfaction levels of the biogas digester system and usage

Perceptions	No. of respondents	%
Fully satisfied	109	62
Partially satisfied	46	26
Not satisfied	21	12
Total	**176**	**100**

The table shows that 109 biogas owners were fully satisfied while 67 were either partially or not satisfied.

All the respondents were then asked to give one most important reason why they were either satisfied or not satisfied during the course of using biogas. Answers were then sorted and grouped to the closest category and then ranked.

Table 17: Full Satisfaction Reasons (n=109).

Satisfaction reasons	**H/H**	**%**
Economic savings from purchasing the other sources of energy.	**51**	**47**
Enough gas to light, cook or run the chaff cutter	**14**	**13**
Slurry is free fertilizer and stimulates algae growth	**11**	**10**
Time saved from sourcing the other sources of energy.	**10**	**9**
Health wise, no backache due to carrying heavy firewood. No coughing, eyes, nose and throat irritation cased by firewood smoke. Clean and soft hands hands because biogas has no dirt. Boil drinking water, especially for the children.	**8**	**7**
Easy to cook, light or run the chaff cutter	**7**	**6**
Trouble free functioning without the need for repairs and maintenance.	**5**	**5**
Less workload in the kitchen like chopping and lighting firewood and charcoal. Easy to clean utensils.	**3**	**3**
Total	**109**	**100**

This table indicates that the most important reason for satisfaction in using biogas was the economic savings from purchasing the other sources of energy (47%). This therefore means energy is one of the major economic burdens in rural Kenya, resulting to energy poverty. None of the kitchens in all the households sampled had a chimney to carry off smoke while cooking using firewood or charcoal. Therefore, lack of adequate smoke exit can be assumed as the cause of the smoke related diseases as identified in the table above.

Table 18: Partial and Non -Satisfaction Reasons (n=67).

Partial and non-satisfaction reasons	**H/H**	**%**
Biogas system dead, not working as efficiently	**14**	**21**

Little or no gas produced	**12**	**18**
Not easy to get maintenance and repair in time	**11**	**16**
Costly to repair	**9**	**13**
Lack of adequate information on maintenance and repairs	**7**	**10**
Unable to store excess gas	**6**	**9**
Plastic tank digester - have to add molasses when gas production reduces during cold seasons, and therefore extra costs.	**4**	**6**
Construction was poor	**3**	**5**
Irresponsible workers to feed the digester correctly	**1**	**2**
Total	**67**	**100**

The table above shows that the top five most non-satisfaction reasons (78%) were based on inefficient and dead biogas systems, lack of repair and maintenance and lack of adequate information.

This study found that the biogas systems efficiency is positively correlated to users' level of satisfaction. Among the respondents, 66%, equivalent to 116 biogas owners said they would recommend to others to install biogas systems. Those who said they couldn't recommend to others cited the dissatisfaction problems they have gone through and therefore wouldn't wish others to go through the same. Sixty four respondents who produced excess slurry said they benefited from selling it to neighbours and it was in high demand because it is better than the ordinary manure.

Research shows that, satisfaction from using biogas is derived from savings on buying charcoal, kerosene, using less firewood, reduced time for collecting firewood and lack of smoke in kitchen (Justus K Laichena & Wafula, 1997). Smoke fumes cause respiratory diseases, headaches, coughing, dizziness and eye diseases. Similarly, biogas improves the quality of life of men, women and children, and user satisfaction is of paramount importance for biogas quality management. (Ghimire, 2013).

6.5.1.1 Perception on Advantages and Disadvantages of Biogas

All the 176 respondents with working and non-working systems were asked to mention 3 main advantages and 3 main disadvantages of biogas systems depending on their experience. Responses were then grouped according to the closest category as shown in the table below.

Table 19: Reasons why Biogas is Advantageous

Rank	Reasons for the advantages / Merits	No. of Households	%Households
1	Economic - Free fuel	176	100
2	Economic - Free raw materials	172	98
3	Economic - Slurry free fertilizer, fish feed	156	89
4	Easy to operate, comfortable to cook	142	81
5	Time saving cooking	136	79
6	Time saving sourcing other fuel	118	69
7	Health – Boil drinking water	94	53
8	Easy to clean utensils	89	51
9	Health – No smoke, coughing	77	44
10	Health - Cleanliness in kitchen, house	72	41
11	Safety - Biogas safer than LPG gas	68	39
12	Health – No back ache	61	35
13	Better quality of life	52	30
14	Gender - Husband and sons can cook	14	8
15	Biogas is prestigious in community	6	3
16	Environmental conservation.	4	2

The table above shows that economic savings, time saving and health are the major advantages of using biogas. Environmental conservation was the least advantage. According to the official from the Ministry of Agriculture, Livestock and Fisheries**,** two of the most likely reason could be that firstly, environment does not benefit a person individually and secondly, lack of awareness on the nexus between using biogas with environmental conservation.

Table 20: Reasons why Biogas is Disadvantageous

Rank	Reason for the disadvantages / Demerits	No. of Households	% Households
1	Hard to get technicians to repair	146	83

2	Lack of enough information	124	70
3	Economic - Lack of subsidy, credit	118	67
4	Economic - Expensive to install	93	53
5	Cant store biogas in cylinder, sell extra	79	45
6	Gas not enough	54	31
7	Components quality not good	42	24
8	Hard to maintain	26	15
9	Hard to know when and where gas leaks	14	8
10	Size installed was smaller than needed	7	4

The table above indicates that lack of adequate and timely repair and maintenance of the biogas systems, lack of subsidy and credit facilities and lack of information were the main demerits of owning the systems. The official from the Ministry of Agriculture, Livestock and Fisheries recommended that the key stakeholders should make more efforts to address these issues

These two tables above signify that there are more merits than demerits for biogas systems. Most respondents had positive attitude towards using biogas.

6.5.2 Biogas Impacts on Users - Time and Workload

To further understand what determines the success of the biogas systems in Kenya, it was important to know what impact it has on the users. The factors considered were time, labour, financial and economic impacts to the users.

One fact that cut across all the respondents was that women were the main beneficiaries of using biogas. This fact was corroborated by secondary data which revealed the same. Women are the ones who do most of household biogas related work and therefore, biogas reduces women workload by up to 3 hours per day and at the same time improves women's' livelihoods (Ghimire, 2013). Biogas use improves women's quality of life. For example, fetching firewood by women is time intensive and tedious, and it is difficult to burn firewood especially if it is wet, during the rainy seasons. However, biogas works even in rainy seasons. Another benefit to women is that husbands and sons enjoy to cook family meals thus helping the women (Sovacool et al., 2015). Health wise, apart from the firewood smoke causing air pollution, it also causes premature deaths of babies (Rajendran et al., 2012).

6.5.2.1 Cooking

When asked what impact biogas had on time spent cooking, 32 households (18%) did not experience any time saving using biogas. These were mainly households which had been using LPG gas previously. They however acknowledged that both LPG and biogas had the same rate and speed of cooking although biogas was free energy. The rest 82% (144 households previously using firewood, charcoal and kerosene), felt that they saved time using biogas. The reduced cooking time by the households was as follows: 43 by 2 hours, 72 by 1 hour and 29 by half an hour. Average time saved using biogas was calculated as follows:-

> 43 saved 120 minutes totalling to 5,160 minutes. 72 saved 60 minutes totalling to 4,320 minutes. 29 saved 30 minutes totalling to 870 minutes. Total time saved by all households was10, 350 minutes. Therefore, by dividing by 144, on average each household saved 72 minutes per day.

Using two or four burner cookers to cooking several meals simultaneously also helped in saving time.

Using biogas as a substitute to traditional energy sources, a household can, on average, reduce cooking time by one hour (Rajendran et al., 2012). Biogas is considered easier and convenient to ignite than firewood. Similarly, heat is not wasted as it can be turned on and off instantly (Day et al., 1990).

6.5.2.2 Collection and mixing of water and dung

Majority of households sampled in Kiambu county had piped water whereas majority in Embu county had dug boreholes as their source of water. The maximum distance noted from the water source to the digester was 20m. Water collection, mixing with dung and feeding the digester on average took an extra 10 min per day. According to Roubík et al. (2016), when the distance from digester and cow sheds is far, accessibility is poor and there are difficulties operating and maintaining of the digester .

6.5.2.3 Collection of Other Types of Fuel

The other types of cooking and lighting fuels commonly used in both counties are agricultural waste, firewood, charcoal, kerosene and LPG gas. According to the the official from KNBS, in Kenya, the type of fuel used is determined by the social economic status of a household. As the social economic status of a household goes up, so does the type of fuel. She categorized the types of fuel into three groups in advancing stages thus:

i) Primitive fuels- Firewood, animal waste, agricultural waste.
ii) Transitional fuel – Charcoal, kerosene, coal
iii) Advanced fuels – LPG, biogas, electricity.

She explained that, most of the Kenyan rural households use both primitive and transitional fuels because they are either freely available, or are affordable by rural standards. LPG and electricity are more common in the urban areas.

It has been previously documented that, in rural Kenya, on average, women take two hours to fetch either firewood or water. However, while biogas use reduces time and labour for collecting firewood, it increases the time and labour to collect water for mixing with cow dung where there is no close and reliable source (Day et al., 1990).

a) Firewood

Respondents in Kiambu said that saved on average two hours daily as they walked long distances to the forest to collect the firewood. In Embu county, time saved was on average one hour per day as they collected firewood from their own farms. Calculations are as follows:-

> Time taken is 2 hours plus 1 hour which equals 3 hours per day. Collecting and transporting firewood home, therefore, on average, took 1 and half hours, equivalent to 90 minutes saved daily.

b) Charcoal

In Kiambu, charcoal was bought from lorries which sell from home to home and therefore there was no time saving impact. In Embu, most respondents burn their own charcoal in their farms using their own trees. However, there are no labour costs in burning the charcoal, because it is done by family members. Preparing the charcoal to be ready for use involves cutting trees, piling, burying, burning, packing and transporting the ready charcoal home. After calculating time saved by using biogas instead of burning charcoal, the results was on average 40 minutes per day. The time saved for charcoal used for one month were calculated as follows;-

> Cutting trees took 12 hours, piling took 4 hours, burying, burning and packing took 3 hours and transporting ready charcoal home took 1 hour. Total time used was therefore 20 hours. This is equivalent to 1,200 minutes. By dividing 1,200 by 30 days (1 month), we find that the time spent per day is 40 minutes.

c) Kerosene

In both counties, kerosene is bought from nearby petrol stations. There are more such stations in Kiambu county than in Embu county which affects the distance travelled to the station. In Kiambu county, respondents on average saved 20 minutes per day whereas in Embu county, they saved 1 and 1/2 hours per day. Therefore, average time saved was calculated thus:-

> Time saved was 20 and 90 minutes totalling to 110 minutes. The average is therefore 55 minutes daily.

d) LPG Gas.

Time saved accessing LPG gas is equivalent to that of kerosene because it is also bought from the same petrol stations. However, use of LPG gas is not so common in most rural households, so it shall be avoided in the calculations as it is likely to skew the results.

6.5.2.4 Cleaning utensils

Respondents said that they saved time cleaning utensils because biogas doesn’t emit black smoke which sticks on the cooking pots while using charcoal, firewood and kerosene. On average respondents in both Kiambu and Embu counties saved 15 minutes daily cleaning utensils.

Research has shown that, since biogas does not emit smoke, cooking pots do not turn black while cooking (Rajendran et al., 2012).

6.5.2.5 Feeding Livestock which Produce Dung (cows, goats, poultry, and pigs).

82% of the 176 households said there was no change in livestock feeding regime and therefore no time impact. The other 18% said they had to feed more to get enough dung with extra time used being 15 minutes on average to collect more feeds like grass or Napier grass. This time saved might skew the results due to the low number of respondents who use more time to feed the livestock but it will be factored anyway.

Table 21: Average Time Saved using Biogas per Household.

Activity	**Average Time saved in minutes per day**
Cooking	72
Dung collection, mixing and feeding digester	- 10
Collection of other 3 types of fuel (without LPG gas) 90+40+55 = 185/3= 62 minutes	62
Cleaning utensils	15
Feeding animal, livestock, poultry, pigs	-15
Total Average Time saved per day per HH	**124 minutes (2hrs 4min)**

This table shows that on average, a family saved 124 minutes per day by using biogas. It is women who mainly carry out those activities so they are the main beneficiaries in the family. However, most respondents claimed there were no direct economic impact on saved time by women apart from the cleaner homes and the crops planted which have nutritional, food security and health impacts.

6.5.3 Economic Savings Instead of Using Other Conventional Fuel Sources

Most respondents said they saved money by using biogas instead of the other conventional fuel sources. Apart from the economic benefits, the biogas produced was used for extra activities such as boiling drinking water, boiling shower water, lighting extra hours e.g. dark rooms and chopping more Napier grass and fodder for livestock. Most of the households used a mixture of the conventional fuels and biogas.

Research has shown that biogas saves cash but does not earn cash. It is not easy to assess the economic impact created by biogas since it is not easy to allocate monetary terms to all benefits derived from biogas since they don't have a defined market value (Bond & Templeton, 2011).

6.5.3.1 Average per Household Savings per Day

After calculations from the answers given by respondents, the average daily savings per household were as follows, compared to biogas burning five hours per day non-stop.

a) Firewood equivalent to biogas used per day saved KSh. 60.
b) Charcoal equivalent to biogas used per day saved KSh. 90.
c) Kerosene equivalent to biogas used per day saved KSh. 120.
d) LPG gas equivalent to biogas used per day saved KSh. 180.

The table below shows the Average annual savings by using biogas instead of the other energy sources.

Table 22: Average Annual per Household Savings by Using Biogas Instead of the Other Energy Sources (365 days)

Fuel	Daily savings in KSh.	Annual savings in KSh. (X 365 days)	Annual savings US $ (@105 KSh)
Firewood	60	21,900	209
Charcoal	90	32,850	313
Kerosene	120	43,800	417
LPG gas	180	65,700	626

This study sought further literature to compare annual savings using biogas as opposed to using traditional sources of energy. According to Sovacool et al. (2015), On average, a family in Kenya can save up to US$ 17 per month using biogas instead of traditional fuels. The annual savings, therefore, is US $204. In addition, biogas has two concrete benefits, that is, economic benefits savings from using other sources of energy, and using slurry, therefore saving from buying inorganic fertilizer (Adeoti et al., 2000).

Further research found that, a rural household family saved US $8 and US $49 on charcoal and kerosene respectively per month (Karanja & Kiruiro, 2010). This translated into a total of US $684 annually for both sources. On average, such a household therefore saved US $342 annually. According to this research, charcoal and kerosene saved a similar household US $313 and US $417 respectively annually (see table 22 above). Both totalled to US $730 annually and therefore, on average, the household saved US $365. This is close to the figure of US $342 calculated by Karanja and Kiruiro (2010), but a higher than the US$204 calculated by Sovacool et al. (2015) above. This could be attributed to the increase of the inflation rate from 2010 to 2015. The three outcomes can therefore be generalised as a fact that, a household saves between US$200-400 annually by using biogas instead of the other traditional sources of energy.

According to the respondents, the average cost of installing an 8m³ size digester is KSh. 80,000 (US$ 762). This was triangulated with secondary data which yielded almost similar average value of Euro 750 (Ghimire, 2013). According to the annual savings summarised in Table 22 above, it indicates that the cost can be recouped by using biogas, for the years shown here below, for each of the four conventional energy sources (assuming no subsidy, maintenance free and no repairs).

a) Firewood use only - 3.7 years (80,000/21,900)
b) Charcoal use only - 2.4 years (80,000/32,850)
c) Kerosene use only - 1.8 years (80,000/43,800)
d) LPG gas use only - 1.2 years (80,000/65,700)

Please note that a combination of using different sources of energy would yield different results.

6.5.4 Other Benefits to Households

As indicated above, the respondents said that using biogas does not earn cash only saves cash. Therefore, some might overlook its financial benefits. The other benefits are defined in this section.

6.5.4.1 Slurry Impact

All the households sampled in Embu county use slurry to do farming. However, only 32% in Kiambu county use slurry because of their small size of arable land, and its mainly used for the vegetable back gardens. They sell the extra slurry to those with largerer farms in Kiambu while in Embu, no one sells the slurry. On average, a 20 litres bucket of slurry is sold at KSh. 50 equivalent to half US dollar. At least, one bucket of slurry iss produced every day, equivalent to the average feedstock added per day. This meant that a farmer can earn up to KSh. 1,500 per month (US$ 14) by selling slurry.

In Embu county, slurry is also used to stimulate the growth of fish feed in form of algae and plankton. According to the respondents practicing fish aquaculture in ponds, the slurry helps to reduce the costs of the commercial fish feeds. Research done shows that, the nutrients in the slurry causes eutrophication (extraordinary growth of algae) in the fish ponds (Rajendran et al., 2012). The fish feed on the algae thus reducing the cost of commercial feeds by 50%. According to the respondents, farmers using commercial feed spend a minimum KSh. 120 per day to feed 1,000 fish. By using slurry in the pond, they spend KSh. 60 per day, therefore, saving KSh. 1,800 per month (US$ 17). Slurry also results in increased fish production in terms of weight and size, as compared to using commercial feeds only. This is because, whereas commercial feeds are limited in quantities fed per day, fish can feed on algae and plankton throughout the day without limit.

Earlier studies have shown that, since the slurry has been completely fermented, it neither consumes oxygen in the pond nor reduces the water quality. Because the colour of the slurry is dark, this helps in the absorption of the heat from the sun which improves the growth of the fish in the pond. Slurry does not expose the fish to diseases because during fermentation, bacteria and parasite eggs in the manure are killed (Food and Agriculture Organization, 1992). Indeed, an earlier research has demonstrated that, after anaerobic digestion of the substrate at an average temperature of 20ºC for 20 days, "total coliforms were reduced by 97.94-100%, *E. coli* populations were reduced by 99.67-100%, and *Salmonella, Cryptosporidium,* and *Giardia* were reduced to undetectable levels" (Rowse, 2011) p. 55.

If livestock manure is not appropriately disposed of, it can cause environmental and health problems like for example pathogen contamination, greenhouse gases, odour and air borne ammonia. Such inappropriate disposal method includes applying the manure directly to the farm without treatment (Abubakar & Ismail, 2012). Biogas slurry is therefore better than raw manure (Dahiya & Vasudevan, 1986).

Bio-slurry saves non-renewable energy, reduces carbon dioxide emissions, improve soil fertility, enhances plant quality and increase plant yields (Cheng et al., 2014). Since slurry is rich in nitrogen, phosphorus and potassium (N-P-K) (Bouallagui et al., 2003), using it instead of manure increases agricultural yield by up to 20%, improves the physical properties of soil and improves the soil water holding capacity (Goud et al., 2016). The slurry nutrient concentrations are easily taken up by plants because it has already gone through anaerobic digestion (Rajendran et al., 2012). Slurry, is more stabilized and less odorous than the ordinary manure (Day et al., 1990). When manure and chemical fertilizers are inappropriately applied on soil, they causes N_2O (Nitrous Oxide) emissions, which can be mitigated by anaerobic digestion. This means that, although, slurry can also cause N2O emissions, the levels are lesser than the other Nitrogen fertilizers. Nitrous oxide is one of the of the greenhouse gases

Due to limitations, this research could not quantify what specific quantity of slurry can replace what quantity on fertilizer. None of the respondents could quantify the actual slurry replacement of the chemical fertilizers. However, previous research has shown that,farmers in the central region of Kenya, use 64Kgs of fertilizer per acre on average. Whereas a bag of 50Kgs. fertilizer on average costs KSh. 2,500, for every acre a farmer therefore spends KSh. 3,200 (64Kgs). However, by using biogas slurry, the farmer saves up to 65% of the costs (Ariga et al., 2008).

6.6 Financial and economic analysis

6.6.1 Financial Analysis

For a person to adopt any new technology, there has to be financial benefit derived from it. To determine such financial impacts on the users, this study did quantitative costs/benefits analysis from the users' responses. In this research however, the outcome could not be verified as it was based on the figures given by the users. In addition, the costs/benefits varied depending on inputs/outputs by the users. Therefore, calculations were based on the average inputs/outputs of all the sampled households.

In order to effectively work out the financial analysis of using biogas, this study held the following assumptions:-

a) The biogas system has an operation lifespan (durability) of 20 years after which it cannot be salvaged. Research has shown that, the economic life of a biogas digester is 20 years where it has zero salvage value (Adeoti et al., 2000).

b) I had to add up all installation costs for all the 120 average size biogas systems ($8m^3$) and divide by the 120 households to get the average installation cost per system. This resulted in an average cost of KSh 80,000 (US$ 760). Operation and maintenance costs were rounded off at 5% of the installation costs.

c) The annual income shall be the average savings from buying the conventional fuels added to the average annual sale of slurry by the 120 households.

d) I did not factor in time saved by women because no monetary benefits were found from the time saved.

e) I factored the interest rate of 6% on investment by assuming that the biogas owner borrows money from a financial institution.

f) Finally, I did not factor in health, environmental and social prestige values derived from using as they could not be converted to monetary values during this research.

Previous studies show that, the cost and benefit ratio is used to determine the financial feasibility to assess the profitability of any project. If benefits are more than the costs, then the project is viable and acceptable (Adeoti et al., 2000). Inputs involve evaluating all the costs of activities involved in the production of biogas while outputs involve the evaluation of the sum of all benefits of the biogas produced (Pöschl et al., 2010).

6.6.1.1 Payback Time

This study sought to calculate the payback time for installing an $8m^3$ digester system. The installation costs of a biogas system is the total construction costs incurred by the system owners (Roubík et al., 2016). The payback is defined as the period of time, from the first day of investment, required to fully recover the investment and operation cost (Adeoti et al., 2000).

According to Roubík et al. (2016), payback time can be calculated using the equation:-

$$\mathbf{D} = \frac{I}{Pr - Npr} \ \textbf{(year)}$$

"Where *D* is the payback time [years], *I* is the biogas installation cost [USD], P_r is the annual benefit [USD] and N_{pr} is the annual operating cost [USD]." (p. 2786).

The calculations yielded the following results for the payback time using the average size digester of $8m^3$:

$$D = \frac{80{,}000}{50{,}850 - 4000} = \mathbf{1.7\ years}$$

In the equation above, the installation cost is KSh. 80,000. The annual benefits were calculated using annual slurry sale (KSh. 1,500 x 12 = KSh. 18,000) added to the average on savings from firewood, charcoal and paraffin as shown in table 22 (KSh. 21,900 + 32,850 + 43,800 = 98,550/3 = 32,850) which totalled to KSh. 50,850. The annual operating costs were 5% of KSh. 80,000 which is KSh. 4,000. The payback time is therefore 1.7 years.

6.6.1.2 Net Present Value (NPV).

This study also calculated the Net Present Value (NPV) of installing an 8m³ digester system, 20 years from the current period.

According to (Adeoti et al., 2000) p. 105, the Net Present Value is the Present value of the benefit minus the Present value of the cost. If NPV is positive, then the project can be accepted and vice versa.

For calculation purposes, according to Adeoti et al. (2000) p.105, the formula for the Net Present Value is:-

$$\mathrm{NPV}_t = \sum_{t=0}^{n} (C_b - C_c)_t (1+i)^{-t}$$

where,

*C*b Cash benefit of the investment

*C*c Cash cost of the investment

(*C*b-*C*c)t Net cash flow in the year (t)

n The calculation period, which is equal to the project life-cycle

i The cut-off discount rate

The Excel spreadsheet table below shows the Net Present Value of an 8m³ biogas system, calculated at an interest rate of 6%.

Interest Rate = 6%

Year	Cash Flow	Present Value
0	-80000	-80000
1	46850	44198
2	46850	41696
3	46850	39336
5	46850	35009
6	46850	33027
7	46850	31158
8	46850	29394
9	46850	27730
10	46850	26161
11	46850	24680
12	46850	23283
13	46850	21965
14	46850	20722
15	46850	19549
16	46850	18442
17	46850	17398
18	46850	16414
19	46850	15485
20	46850	14608
NPV		420256

The calculations were done as follows:

Column 1 shows the years of the biogas lifespan (20). Column 2 shows the initial investment figure (-80,000) and under it, the annual returns (savings) using biogas, having ignored inflation rates and assuming everything remains constant. Column 3 is the present value of each of the cash flows per year calculated at an interest rate of 6%.

Therefore, the investment of KSh. 80,000 today, earning KSh. 46,850 constantly per year, has an NPV of KSh. 420,256 in 20 years. Therefore, biogas has positive returns and is worth investing in.

6.6.2 Economic Analysis

Research has shown that there is a positive correlation between per capita energy consumption and economic prosperity and quality of life in rural areas. Renewable energy can achieve both (Roubík et al., 2016). Some of the costs and benefits derived from using biogas are not limited to the users only. These costs and benefits can also be extended to the wider community. Some of the benefits of using biogas that also impacts on the wider society include cleaner environment, conservation of forests, increased food productivity, reduced carbon emissions/global warming , improved health, economic growth, poverty alleviation, employment opportunities, free time for women, better lifestyle and food security (Rajendran et al., 2012).

In general terms, based on financial analysis worked out above, it is possible to make an assumption that biogas also has economic benefits and therefore is economically viable.

CHAPTER 7
CONCLUSION

There is still a potential to increase biogas technology adoption by the rural households in Kenya. This will be made possible by reducing the installation costs, availing the farmers with information on the technology, subsidy and credit facilitation, adequate extension service personnel and increasing promotional activities by the key stakeholders including the government, NGOs and the private sector. Biogas owners should be trained on the operation and maintenance of the biogas systems.

This research made several findings for the most likely groups in the society to install biogas digester systems in rural Kenya. They are those aged between 30 and 59 years, those whose household members are between six and eleven, those whose main occupation is either self-employment or agriculture, those who own between one and five acres of land and those owning between two and five cows. However, there was no evidence that increase in educational level increases the likelihood to adopt the biogas technology.

The most common sizes of the biogas digesters sampled were 4, 6, 8, 10 and12 m^3. The recommended construction and installation methods are important to ensure the success of the biogas systems. Other important activities to avoid failure of the digester systems are unclogging condensed water from the gas pipe using a bottle trap, cleaning the biogas stoves and lamps to remove any particles that might block the gas, sealing any gas leakages, all the way from the digester to the point of use, including pipe joints and valves, and regularly removing the exhausted slurry from the outlet. Similarly, manure and water should be mixed at the ratio of 1:1.

Economic benefits derived from saving money and time were found to be the main motivating factors for installing biogas systems.

For improved biogas production, fresh cow dung should be used as feedstock instead of dry dung. Feedstock should be a minimum of 20Kgs per day and the substrate temperature should not be lower than 10°C. The hydraulic retention time should be determined by the size and the volume of the biogas digester. In addition, co-digestion is better than mono-digestion because it helps increase biogas production. Seeding, adding charcoal and molasses to the substrate also speeds up biogas production.

Just like any other technology, biogas technology experiences faults within the subsystems. These faults affect biogas productivity and stability. As the biogas system ages, so does the frequency of the faults increase. It is therefore necessary that the recommended solutions to the faults are used to rectify the problems. Similarly, the inlet and the outlet should be symmetrically in the opposite ends of the digester.

The ideal substrate temperature for maximum biogas production should be between 35-40°C when anaerobic bacteria work best, and biogas production ceases if the temperature goes below 10°C. Similarly, the pH range between 6.5-7.5 is the most ideal for optimum biogas production, and therefore cow dung is the best feedstock as its pH of 7.4 falls within this optimum range.

A water trap is necessary to remove any condensed water in the piping system. This condensed water, if not removed, slows down or even stops the gas flow towards the point of use. Additionally, gas flow reduces or stops if the substrate is not regularly stirred in order to remove the scum that forms in the digester. However, the stirring should be moderate and not excessive or minimal as this can affect the anaerobic bacteria. The diameter of the gas pipe from the dome to the point of use should reduce from 1" to 3/4" to 1/2" and finally to 1/4" in order to increase the gas pressure. However, the piping distance is insignificant. More research is necessary to come up with methods to store and transport excess biogas produced.

When a yellow flame is observed, it is an indicator that enough gas has not been produced and therefore the gas pressure is low. This can be mitigated by adding more feedstock to increase biogas production. When adequate biogas is produced, the flame slowly turns to blue.

Biogas is almost as equal in efficiency just as LPG gas at 57%. Similarly, biogas light emission is also efficient because it is comparable to similar light emission of an ordinary light bulb of up to 75 watts. Biogas also produces both mechanical and electrical energy and can be upgraded to be used as vehicle fuel.

Desulphurization to remove hydrogen sulphide in biogas is important to avoid corrosion of machine parts during internal combustion. Removal of hydrogen sulphide will also reduce the corrosion, rusting and clogging of the biogas burners and lamps.

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APPEDIX 1

QUESTIONNAIRE FOR COLLECTING PRIMARY DATA

Introducing myself.

Hallo. My name is Stephen Ngugi Wamwea from Norwegian University of Life Sciences (NMBU). I am doing research for my Master thesis on the success and failure of biogas systems in rural Kenya. This will help me understand more about the conditions under which biogas can work best. The information you give me will be confidential and will be used solely for my Master thesis and not for any other purposes. Your household was selected randomly from all the households that have installed biogas digesters for over five years. I would like to ask you about the functioning of your biogas system. Your participation in the research is voluntary and you can withdraw at any point, including the information you have given. If you would like to ask me any questions regarding this survey please feel free to do so. Thank you.

A: Household information

1. County (a) Kiambu............................ (b) Embu………...........…

2. Head of the household: (a) Man……...…… (b) Woman…....………

3. Age (s) in years: Man (a) 18-30....... (b) 31-40........ (c) 41-50........ (d) Over 50..........
   Woman (a) 18-30....... (b) 31-40........ (c) 41-50........ (d) Over 50......

4. Main occupation: Husband (man)…………………Wife (woman)……........………

5. Education level:
   Husband (man): (a) Uni…..... (b) College......... (c) Sec...... (d) Pri....... (e) None...
   Wife (woman): (a) Uni…..... (b) College....... (c) Sec....….. (d) Pri....…. (e) None....

6. Number of household members: Adults…………….Children………………

7. Number of livestock:
   Cattle: Mature……......young……...…. Total……...….

Goats: Mature………......young……...…. Total……....….

Sheep: Mature………......young……...…. Total……....….

Pigs: Mature………......young……...…. Total……....….

Poultry: Mature………......young……...…. Total……....….

Others (specify)............................ Mature………......young……...…. Total……....….

8. Land size

(a) Under 1 acre....................

(b) 1-5 acres....................

(c) 5-10 acres....................

(d) 10 -15 acres....................

(e) Other (specify)....................

9. Gross household income per month (Kenya Shillings):

(a) Under 5,000....................

(b) 5,000 - 10,000....................

(c) 10,000 - 15,000....................

(d) 15,000 - 20,000....................

(e) Other (specify).........................

10. Source(s) of water for domestic/farm use

(a) Piped…………………..

(b) Obtained from bore hole…………………..

(c) Obtained from the river/dam…………………..

(d) Rain water harvested in a tank…………….

(e) Other (specify)..

11. Distance to the water source in Kilometres...

B: General information on biogas

1. What type of digester do you have? (a) Fixed dome......... (b) Plastic tubular.......
2. When did you install the biogas digester (years ago)? (a) 5-7... (b) 8-10...(c) Over 10..
3. Is your biogas system still working? (a) Yes, fully….Yes, partially.... (b) No……
4. If it has stopped working, how many years was it working?.......................................
5. What are the reasons why your digester is (either) still working/stopped working?

   ....

   ....

   ....

   ....

6. If your system is not/stopped working, would you install another digester?

   (a) Yes..........…. (b) No...................…

   What are the reasons?

   ....

   ....

   ....

7. What do you use your biogas for? (a) Cooking....... (b) Lighting.......... (c) Heating.....

   (d) Others (specify)...

8. How long (in hours) do you use biogas for each of the above daily?

   (a) Cooking............ (b) Lighting.......... (c) Heating.............

   (d) Others (specify)...

9. Is the gas enough? (a) Yes………. (b) No…….

10. Were you aware of biogas technology before it was introduced to your household?

    (a) Yes………. (b) No…..….

11. How did you come to know about biogas technology?

    ....

    ....

    ....

12. What were the reasons that made you install the biogas digester?

....

....

....

13. Who installed your digester? (a) Unskilled labourer............. (b) Skilled and trained technician..................

14. Did you find the installation technically demanding? (a) Yes …… (b) No…..

If yes, what aspects of this technology requires more technical assistance

....

....

....

15. Were you trained on the maintenance of the biogas system? (a) Yes…... (b) No………

16. Did/do you receive after sales service? (a) Yes…...... (b) No…........…

17. Is/was the service technician readily available when you need them? (a) Yes.. (b)No..

18. Were the materials to install the unit easily available? (a) Yes …… (b) No…..

If not, which components were not easily available and why

....

....

....

19. What was the total cost for installing the digester? Kenya Shillings............................

How much did you contribute towards the installation? Kenya Shillings....................

Who contributed the rest and how much?...

20. Did you feel the cost was affordable to you? (a) Yes …… (b) No…..

If not, what were the reasons?

....

....

....

21. What is/are the main type of biodegradable raw material(s) (e.g. dung) have you been using to feed the digester and where do you obtain them from?

....

....

....

22. Are/were the biodegradable raw material(s) easily available? (a) Yes … (b) No…..
If not, what were the reasons?

....

....

....

23. Are/were the materials enough for your daily feeding of the digester? (a) Yes …(b) No..
If not how and from where do/did you obtain the rest of materials?

....

....

....

24. Is/was the water to maintain the digester sufficient? (a) Yes … (b) No…..
If not how and from where do/did you obtain the rest of the water?

....

....

....

25. How often do you feed the digester and what quantity each time?..........................

26. How often do you need to empty/clean your digester?...

27. What are the technical problems that you experience with your digester, if any (e.g. leakage)?

....

....

....

28. What measurements do you use to test the digester, if any (e.g. pH and temperature)?

....

....

....

25. Are there other problems that you think affect the success of your biogas technology?

....

....

....

C: Socio-economic and cultural issues

1. Are there social taboos associated with the raw materials you use? (a) Yes…(b) No
If yes, please explain

....

....

....

2. What are the benefits you have obtained after adopting the biogas technology? List in order of importance.

i. ……………………………………………………………………………

ii. ……………………………………………………………………………

iii. ……………………………………………………………………………

iv. ……………………………………………………………………………

v. ……………………………………………………………………………

vi. ……………………………………………………………………………

3. What were your main sources of energy before introduction of biogas? List in order of importance

i. ……………………………………………………………………………

ii. ……………………………………………………………………………

iii. ……………………………………………………………………………

iv. ……………………………………………………………………………

v. ……………………………………………………………………………

vi. ……………………...…………

4. How much fuel-wood (Charcoal or fire-wood), paraffin, LPG gas, electricity or other sources of energy were you spending monthly and the total cost (including time spent) before and after installing the biogas digester (Kenya Shillings)?

Source	**Before**	**After**	**Difference**
Charcoal			
Fire-wood			
Paraffin			
LPG Gas			
Electricity			
Other source			
Other source			
Total			

5. How much does it cost you to maintain your biogas system monthly in terms of cash and labour in Kenya Shillings?

Cost	**Amount in Kenya Shillings**
Cash	
Water fetching labour	
Digester feeding labour	
Maintenance labour	
Other costs	
Other costs	
Other costs	
Total costs per month	

6. About how much do you rate biogas has helped to replace your other sources of energy (including time spent)? Approximate each using 0%, 25%, 50%, 75%, 100%.

Source	% replacement
Charcoal	
Fire-wood	

Paraffin	
LPG Gas	
Electricity	
Other source	
Other source	

7. Who in the family do you think from your perception has benefited most from biogas? List in order starting from the biggest beneficiary among Husband (man), Wife (woman), Children, All.

i. ……………………………

ii. …………….…………..

iii. …………..………………

iv. ………………...………..

8. Are there some financial commitments you could not meet but you are now able to by using biogas? (a) Yes ….... (b) No…......

If yes, please explain.

....

....

....

9. How has your general welfare/livelihood changed since you adopted biogas?

(a) Not changed……..... (b) Little…………..(c) Much.......... (d) Very much……………….

If changed, please explain how

....

....

....

10. Do you use the slurry from the digester in your farm as fertilizer? (a) Yes .... (b) No…....

11. If you use the slurry in the farm, has it replaced the chemical fertilizer costs? (a) Yes …. (b) No…..

If yes, approximately by how many kilograms?

Fertilizer used before using the slurry.................. Kgs. Current fertilizer use................Kgs.

Difference............................Kgs

If no, how do you use the slurry?...

12. Would you recommend biogas technology to a person who has not installed yet?

(a) Yes …....... (b) No........…...

13. According to you, what are the advantages of biogas?

....

....

....

14. According to you, what are the disadvantages of biogas?

....

....

....

APPEDIX 2

KEY INFORMANTS QUESTIONAIRE

Biogas system (Plastic Tubular and Fixed dome)

1. What are the components of a biogas digester?
2. How does digestion work best in order to produce biogas efficiently?
3. How long does the digester take to install/construct?
4. What is the cost of installing a biogas digester?
5. Who installs biogas digesters in the area (skilled or unskilled technicians)?
6. Are farmers trained on the maintenance of the biogas systems?
7. Do the farmers readily get after sales services?
8. What are the main substrate materials used to feed the digester and are they readily available?
9. After how long is biogas produced after installation?
10. If plastic digester, what is the material made of?
11. How regularly should the digester be emptied and cleaned?
12. How long can the digester operate before it becomes unfit for use (lifespan)?
13. What makes the digester work efficiently and produce the expected optimum gas?
14. What is the retention period of the substrate in the digester?
15. What is the ideal temperature for biogas production?
16. How much dung does an ordinary cow produce per day and how much gas can be produced from that dung?
17. What is the mixture rate of biodegradable materials and water to feed the digester?
18. What is the conversion rate of the substrate to biogas in kilograms?
19. How regularly should the digester be fed with the substrate?
20. What amount of gas produced is enough for an ordinary family? (Get specifications).
21. What are the main uses of biogas in an ordinary household?
22. What can extra biogas produced be used for?
23. What is the cost of biogas compared to other sources of energy and how much does biogas replace the other sources of energy?
24. How much chemical fertiliser is replaced by the slurry produced by the digester?
25. What appliances can ran on biogas in a rural household setting?
26. Are there social taboos associated with the biogas digester systems?

27. How does biogas use change the livelihoods of the local people who have adopted it?
28. What are the causes of digester failure?
29. How are these problems solved?
30. What are the advantages of biogas?
31. What are the disadvantages of biogas?