DETERMINANTS OF ADOPTION AND MANAGEMENT OF BIOGAS IN KIAMBU COUNTY

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DECLARATION

This project is my original work and has not been presented wholly or partly in any other university for any award.

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DEDICATION

This thesis is dedicated to the 2004 Nobel Peace Prize Winner, the late Prof. Wangari Maathai for her passion and great contribution to our dear environment.

“Nature is kind, but could be unforgiving if abused”

Prof. Wangari Maathai (1940-2011)

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LIST OF ABBREVIATIONS AND ACRONYMS

ABC	American Biogas Council
ABPP	African Biogas Partnership Program
ACP	African Caribbean and Pacific
AESL	Alternative Energy Systems Limited
AFM	Authority for the Financial Markets
BAG	Biogas Association of Ghana
BP	British Petroleum
BPD	Barrels Per Day
BSP	Biogas Support Programme
CADP	County Annual Development Plan
CELP	Centre for Environmental Law and Policy
CBO	Community Based Organisation
CCAFS	Climate Change, Agriculture and Food Security
CEF	Conserve Energy Future
CET	Clean Energy Technology
CGIAR	Consultative Group on International Agricultural Research
CGK	County Government of Kiambu
CH_4	Methane
CIDP	County Integrated Development Plan
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DOI	Diffusion of Innovation

EBA	European Biogas Association
EC	European Commission
EKC	Environmental Kuznets Curve
EMCA	Environmental Management and Coordination Act
ERC	Energy Regulatory Commission
EU	European Union
FGD	Focused Group Discussions
FIT	Feed in Tariff
FICCF	Finance Innovation for Climate Change Fund
GBA	German Biogas Association
GBM	Green Belt Movement
GDP	Gross Domestic Product
GEF	Global Environment Fund
GESIP	Green Economy Strategy and Implementation Plan
GETF	Green Energy Task Force
GHG	Green House Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Development Agency)
GK	Government of Kenya
GTZ	Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Corporation)
H_2S	Hydrogen Sulfide
HEP	Hydro Electric Power

IAP	Indoor Air Pollution
ICF	International Climate Fund
IEA	International Energy Agency
IFG	International Forum on Globalization
IGAD	Inter Governmental Authority on Development
IHA	International Hydropower Association
IT	Institutional Theory
IUCN	International Union for Conservation of Nature
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KAM	Kenya Association of Manufacturers
KAP	Knowledge, Attitude and Practices
KARI	Kenya Agricultural Research Institute
KEBS	Kenya Bureau of Standards
KENAFF	Kenya National Farmers' Federation
KENDBIP	Kenya National Domestic Biogas Implementation Program
KENFAP	Kenya National Federation of Agricultural Producers
Kgs	Kilograms
KII	Key Informant Interviews
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KNBS	Kenya National Bureau of Statistics
KP	Kenya Power
Kshs	Kenya Shillings
KW	Kilo Watts

kWh	Kilo Watt Hour
LMCP	Last Mile Connectivity Project
LPG	Liquefied Petroleum Gas
MDGs	Millennium Development Goals
MOE	Ministry of Energy
MOEP	Ministry of Energy and Petroleum
MEWNR	Ministry of Environment, Water and Natural Resources
MW	Mega Watts
NACOSTI	National Commission for Science, Technology and Innovation
NCCAP	National Climate Change Action Plan
NCCRS	National Climate Change Response Strategy
NEED	National Energy Education Development
NEMA	National Environment Management Authority
NEP	National Environment Policy
NEPAD	New Partnership for Africa's Development
NEPP	National Energy and Petroleum Policy
NGO	Non Governmental Organisation
NH_3	Ammonia
NO_x	Nitrogen Oxide
OECD	Organisation for Economic Cooperation and Development
OSSREA	Organisation for Social Science Research in Eastern and Southern Africa
PEOU	Perceived Ease of Use
PRSP	Punjab Rural Support Program

PU	Perceived Usefulness
RBT	Resource Based Theory
RDT	Resource Dependence Theory
REA	Rural Electrification Authority
REDD+	Reducing Emissions from Deforestation and Degradation
REP	Rural Electrification Programme
RERM	Renewable Energy Road Map
SACCO	Savings and Credit Cooperative Society
SBA	Swedish Biogas Association
SBSECC	Strengthening Business Society Engagement in Climate Change
SDGs	Sustainable Development Goals
SEAI	Sustainable Energy Authority of Ireland
SE4All	Sustainable Energy for All
SEA	Swedish Energy Agency
SEFA	Sustainable Energy Fund for Africa
SEP	Special Energy Programme
SMEs	Small and Medium Enterprises
SMW	Solid Municipal Waste
SNV	Stichting Nederlandse Vrijwilligers (Netherlands Development Organisation)
SO_2	Sulphur Dioxide
SREP	Scaling-up Renewable Energy Programme
TAM	Technology Acceptance Model
UN	United Nations

UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
VAT	Value Added Tax
VEP	Visionary Empowerment Programme
WAC	World Agro-forestry Centre
WBA	World Bio-Energy Association
WBA	World Biogas Association
WCA	World Coal Association
WHO	World Health Organisation
WMI	Wangari Maathai Institute
WNA	World Nuclear Association
wPOWER	Partnership on Women's Entrepreneurship in Renewables
WWF	World Wildlife Fund
WWTP	Waste Water Treatment Plant

ABSTRACT

Biogas is an important source of green energy and the growth of its production in Kenya is mainly supported by co-digestion of manure. Economic and institutional factors have been identified to affect the success of the Kenyan biogas sector. This study dwelt on adoption of biogas technology in Kiambu and aimed to analyze the demographic factors that affected the adoption of biogas technology, evaluate the governance issues on the same and determine the perceived benefits of adoption of the technology. Data was collected by surveying 416 (n=208 households producing biogas and n=208 households not producing biogas). Households were randomly selected using the transect line survey of every fifth household in four sub-counties in Kiambu. Equal distribution of sampled households was ensured for each ward sampled (n=13 for households producing biogas and n=13 for households not producing biogas). Both quantitative and qualitative data were collected. Quantitative data was analysed using descriptive statistics while qualitative data was tested using Chi-square test ($P \leq 0.05$). Biogas technology adoption rate in Kiambu was low (25%) and this was even lower in female-headed households (33%). Other demographic factors that significantly influenced biogas adoption in Kiambu included age of the household head, the main farming activity practiced, land ownership tenure, livestock keeping activity, and household income level (n=416, $P \leq 0.05$). However the respondents' education level did not significantly influence the adoption rate. Respondents' knowledge, attitudes and practices on adoption of biogas and its governance indicate that 87.64% of the respondents knew about biogas and its usefulness. Only minority (21%) were aware of the regulatory legislation and majority (85%) did not comply with the regulations. As stated, biogas adoption in Kiambu was low (25%) and that majority of those adopting the technology (98%) were not organized into associations. There was also moderate (50%) institutional support for biogas adoption. Results show that willingness to adopt biogas technology is high in Kiambu (90%), and the felt value addition in being members of biogas user associations is also high (95%). However, the regulation process is weak (21%). Both adopters and non-adopters were aware of benefits of adopting biogas technology and pointed out environmental, social and economic benefits (n=80; $P \leq 0.05$; $X^2=84$). Adopters cited the improved farm fertility and clean environment through utilization of slurry from the biogas bio-digesters in farms (n=40; $P \leq 0.05$; $X^2=91$). All respondents indicated that adoption of biogas technology would help mitigate climate change (n=80; $P \leq 0.05$; $X^2=67$). All respondents also indicated that biogas reduces indoor pollution (n=80; $P \leq 0.05$; $X^2=92.4$). Biogas was indicated to offer the benefit of manure waste management (n=80; $P \leq 0.05$; $X^2=89.1$). Respondents stated that adoption of biogas would help save on time used to fetch firewood (n=80; $P \leq 0.05$; $X^2=94$). It was highly rated on reliability (n=80; $X^2=67$) and efficiency (n=80; $X^2=60$). Adopting respondents indicated biogas is economical (n=40; $X^2=56$). All respondents cited the benefit of job creation (n=80; $X^2=53$). It is recommended that policy on biogas adoption is not only based on the need to decrease environmental pollution but also the need to address the challenges arising from demographic disparities in the communities. Weak regulation led to low adoption of biogas technology in Kiambu but a potential exists for its enhanced adoption especially through increased institutional and legislation support. There is also need for awareness creation on governance instruments and need to address the capacity gaps existing. Incorporation of awareness of perceived benefits could prove useful in co-designing and co-implementation of governance and management frameworks for biogas in Kiambu County and Kenya at large.

CHAPTER ONE

1.0 INTRODUCTION TO THE STUDY

1.1 Background

Energy is a critical component of human life and without it many activities would ground to a halt because it is at the core of the social-economic development of any nation (Bloyd and Bloyd, 2001; Surendra, *et al*, 2014). Energy occupies a central position in society because it touches and influences all aspects of human life (UN, 2015; Alayi *et al.*, 2016). For a country to attain any measure of development in the modern sense, energy has to play a decisive part. As a key element of development, access to energy plays a significant role in social economic progress. According to Kenya's Sessional Paper Number 4 on Energy (May 2004) drafted by the Ministry of Energy and Petroleum (MOEP) the performance of the energy sector is a great determinant of the government's development strategies.

The National Energy and Petroleum Policy (NEPP) also developed by MOEP in 2015 noted that there is a correlation between energy consumption and economic growth and development. Higher demand for commercial energy is usually an indicator of increased economic activities which results into an equally high level of Gross Domestic Product (GDP). As a key driver of social-economic development, the type of and manner in which energy is generated and utilised will have a strong bearing on the sustainable nature of development. The projected increase in demand for energy in Kenya of up to 15,000 Mega Watts (MW) by 2030 calls for investment in alternative sources like biogas (Hussein, 2014).

1.2 Global, Continental and National Perspective of Biogas

Countries that have adopted biogas technology do so due to various reasons but on the whole the factors can be divided into two: the desire to minimize negative impacts and challenges of fossil fuels and the need to provide energy to off-grid communities (Sakah and Kimengsi, 2012; Lybæk, 2013; Berhe and Hoag, 2017; Scarlat *et al*., 2018) . For Kiambu County, as in many parts of the developing world, the main desire was to provide sustainable energy to the community. Developed countries use biogas principally for generation of electricity to run industries and as fuel in the transport sector (Momanyi, 2015; EC, 2016; Scandinavian Biogas, 2016). Poor countries produce biogas mainly for cooking and heating primarily because of energy poverty caused by low electricity distribution from the national grid (Kileo, 2014; Surendra *et al*., 2014; Ngo *et al*., 2017).

Several barriers have been experienced by different countries as they adopt this technology. In Kenya, demographic factors such as age, education and income levels have been identified as among the major causes of low uptake of biogas technology (Gitone, 2014; Obwogi, 2014 Momanyi, 2015; Mbali *et al*., 2018) and that focusing on their resolution would prompt diffusion of this form of green energy. These factors seem to cut across the developing countries (Iqbal *et al*., 2013; Mital *et al*., 2018) but in the developed countries the major barriers to diffusion of biogas technology include conflict in political priorities and oscillation of strategic objectives (Fenton and Kanda, 2017). Where barriers are similar, comparable solutions may be adopted although this may also depend on local dynamics.

Different resources are used to produce biogas depending on their availability and they include animal waste, municipal waste and agricultural residues. In Africa, Asia, Latin America and the developing world as a whole, the principal feedstock for production of biogas is cattle dung while in the European Union (EU) energy crops are increasingly being used as the major substrate **(**EC, 2016; Armah *et al*., 2017). This could be because developed countries have resources to explore alternative feedstock and since they have attained food security they can afford to allocate land to grow energy crops unlike the poor countries where land is used to grow food. Apart from cattle dung, waste from buffaloes is used to produce biogas in Asian countries like India and Nepal (Carotenuto, 2012; Karttek *et al*., 2014). Availability of technology has made it possible for co-digestion of biodegradable substrate to be used in production of biogas. Western countries are known for producing biogas through co-digestion of different feedstock as opposed to most African countries where one type of waste is used. This is what has partially contributed to those countries producing higher quantities of gas; the quality is also higher because the gas has combined synergies from multiple substrates and this leads to an even cleaner environment (Abdoli *et al*., 2013; Müller-Stöver *et al*., 2016).

In Africa the trend is to promote co-digestion so as to maximize on the locally available resources (Austin and Morris, 2011). This ought to be encouraged as one strategy of up scaling adoption and utilization of this technology in Kiambu County. Municipal waste is potentially one of the key sources of feedstock for producing biogas in Africa but utilization of this resource is hampered by the absence of suitable sewer systems (Austin and Morris, 2011; CIDP, 2013 – 2017; CGK, 2017).

Different stakeholders at the global level are brought together by the World Biogas Association (WBA). The mission of this body is to raise global awareness about biogas and encourage its uptake as a strategy of confronting contemporary environmental, social and economic challenges (WBA, 2017). By bringing experiences from different parts of the world, WBA offers critical support towards development of biogas at the global stage. WBA activities can be considered to be part of the governance structure in management of biogas at the global level.

Government support in success of the biogas sub-sector is critical as seen in examples from the European Union (EBA, 2013; Torrijos, 2016; Scarlat *et al*., 2018). Some governments in the poor countries face financial challenges that compel them to rely on donor support to fund their biogas projects (Lybæk *et al*., 2017). By creating an enabling environment, governments can also attract private sector investors who would then boost adoption of biogas and all its attendant benefits (Akinbomi *et al*., 2014).

Globally biogas has brought multiple benefits where it is adopted, such as being a clean source of energy (Zhang *et al*., 2015; Mengistu *et al*., 2016; SEAI, 2017); it has helped in reducing carbon emissions especially where it replaced wood fuel and animal dung as the primary energy sources for cooking and heating (Muriuki, 2014; Sarker *et al*., 2014; Somanathan and Bluffstone 2015) is a strategic waste management approach (Bond and Templeton, 2011; Das *et al*., 2017) among others. Economically biogas adopters have benefited from carbon credits that are paid for their contribution in reducing carbon emissions responsible for global warming and climate change. The biogas sub-sector has created various employment opportunities through which people earn an income (Findeisen, 2015; Momanyi, 2015; ABC, 2018).

Potential exists for biogas to contribute significantly to sustainable development in environmental, social and economic realms given the numerous substrates that lie unutilized across the globe, emerging new technologies in the sub-sector and growing interest in clean energy among other positive attributes (Bond and Templeton, 2011; Kiplagat *et al*., 2011; EBA, 2013; Akinbomi *et al*., 2014; Alayi *et al*., 2016; Scandinavian Biogas, 2016; Lybæk *et al*., 2017).

For this to be successful legal, policy and regulatory instruments that will steer sustainable exploitation of biogas are necessary. In the Kenyan context there is need for policy guidance on issues like production, transportation, storage, and utilization of biogas so as to enable it play a significant role in the local energy mix. A wider energy mix improves access to energy, boosts security of supply as well as raising people's level of energy autonomy that can be part of the foundation for future energy sustainability for all, and this role can be considerably handled by biogas (Bloyd and Bloyd, 2001).

1.3 History of Energy

Early man discovered fire that was used to cook food and keep him warm using firewood. Over time there have been many discoveries of different forms of energy that are invented according to needs of contemporary society and available technology. The first source of energy to be used for transportation was wind and Egyptians are believed to be among the first people to use sails to capture wind that enabled their boats to move on water (The NEED Project, 2016). In terms of processing food, windmills and water wheels were used to grind grains (Gasch and Twele, 2012).

Coal has been used for hundreds of years but it became the main source of energy during the Industrial Revolution (19^{th} – 20^{th} century) that saw major European powers invest in various industries (Timmons *et al*., 2014). The expansion of industries led to a surge in demand for energy that saw coal mines being developed to a great extent in countries like Britain, France and Germany. It was used to power steam engines, heat buildings and produce electricity. Today coal is used mainly for electricity generation, steel production, manufacturing of cement and as a liquid fuel (WCA, 2017).

Large deposits of coal were discovered in Kitui County, Kenya in 2012 and this resource is expected to form a significant part of the country's energy mix given that its cost will be Kshs 7.5 per unit compared to diesel-fired plants that charge Kshs 20 per unit (Diakonia, 2014). Despite protests from environmentalists, construction of Kenya's first coal power plant commenced in Lamu County in 2017 and on commissioning it will produce 1,050 MW of electricity (MOEP, 2018). It has to be acknowledged that coal has considerable negative human and environmental impacts from the time it is mined, transported, stored and burned. These impacts become more pronounced when coal is used to generate electricity because in the process it emits poisonous gases such as sulphur dioxide (SO_2), nitrogen oxides (NO_x) and carbon dioxide (CO_2). Coal emits more Green House Gases (GHGs) than any other form of fuel

(Kristoferson, 1992). However these challenges can be overcome by adoption of clean coal technology through which the impacts are mitigated (OECD/IEA, 2008).

Oil and its associated fuels began to be used as alternatives to coal from the 1860s onwards. The 19th century saw oil replacing coal and today the “black gold” has become the predominant source of energy the world over. From the 1850s when commercial exploration of oil began to date, it is estimated that the world has consumed more than 135 billion tonnes of crude oil and the figures are still rising (Gray, 2017). The global consumption of oil is approximately 97.8 million barrels per day (bpd), with China being the leading consumer (IEA, 2018). China’s thirst for oil is fueled by the Asian giant’s rapid economic growth that has gone in tandem with increased demand for additional energy.

Use of Hydro Electric Power (HEP) goes back to the Han Dynasty in China (202 BC and 9AD) and today this form of energy is widely used across the globe (IHA, 2016). One disadvantage of HEP is that power generation is affected by weather conditions. When water levels go down due to drought, less power is generated and the same happens when rivers are frozen in winter. Similarly, siltation of dams leads to interruption in production of electricity.

Nuclear energy was developed in the 1940s and commercial production started in the 1950s. Today about 11% of global electricity consumption is derived from nuclear reactors (WNA, 2018). Kenya hopes to generate 1,000 MW of electricity from nuclear energy by 2025 (MOEP, 2018).

1.4 Fossil Fuels versus Renewable Energy

Despite growing interest in renewable energy and concerns about the use of fossil fuels such as energy security and climate change, demand for oil will maintain an upward trend and the global economy will continue relying on oil more than any other fuel for the foreseeable future (Bahgat, 2006; Nötzold, 2012). It has been predicted that hydrocarbons will retain their dominance, supplying 80% of global energy requirements up to the year 2035 (BP Energy Outlook, 2016).

This is partly because oil is a widely found source of energy, more discoveries are still being made, has ease of use and the infrastructure for its extraction, transportation, production and use is already in place across the globe compared to other forms of energy. The huge amount of resources required to shift from fossil fuels to green energy, divergent environmental, political and economic interests of various stakeholders mean that it will take a considerably long time for the entire process to be accomplished, if at all (El Solh, 2010; Timmons *et al*., 2014).

Being a predominantly agricultural area, Kiambu has plenty of resources, which if well managed and utilised, could contribute to increased adoption of biogas as a source of clean energy for a cleaner environment. Biogas is a green energy produced through anaerobic fermentation of organic matter. It is a technology that has been in existence for many years and was now spreading to many parts of the world mainly due to challenges experienced through use of conventional sources of energy such as environmental pollution, increased global demand for energy and lack of security of supply (Achinas *et al*., 2017). The increasing popularity of biogas is mainly due to its multiple benefits compared to fossil fuels (Raboni, and Urbini, 2014).

1.5 Biomass Utilization in Kenya

Biomass contributes 70% of Kenya's energy requirements while 90% of the rural population depends on wood fuel, notably firewood as their major source of energy (Mugo, and Gathui, 2010; Kiplagat *et al*., 2011; ERC, 2012; Mwangi, 2013). In the urban areas more than 80% of mainly low income residents rely on charcoal as their primary energy source (WAC, 2018) Because demand for wood fuel outstrips supply, this has adversely affected the environment in terms of reduced tree cover, pollution and soil erosion among other negative impacts (MEWNR, 2013). Social and economic impacts have also been felt with regard to gender-based energy hardships that adversely affect women and girls and the increasing cost of energy that particularly affect poor households. These are some of the challenges that have motivated stakeholders to show more interest in the development of biogas technology. The government of Kenya instituted its Energy Policy through the Sessional Paper No. 4 of 2004 that specifically pledged to support development of biogas technology at domestic and institutional levels (MOEP, 2004).

Biogas technology is highly developed in Western countries and forms a significant portion of their energy mix. In the European Union, Germany produces the largest amount of biogas that is used mainly for generation of electricity for domestic and industrial use (Findeisen, 2015). The technology is also widely used at the domestic level in China, India and Nepal where government facilitation has seen its rapid adoption (Karki *et al*., 2015).

In Kiambu County and Kenya as a whole, biogas adoption is still low as will be explained in this study. The main feedstock for biogas production in Kenya is cattle dung and the gas is used mostly for cooking and heating. Recently there have been efforts to generate biogas on industrial scale and a good example is the Gorge Farm Energy Park at Naivasha in Kenya's Rift Valley region. The facility is the largest biogas plant in Africa and it uses horticultural waste to generate 2.5 MW of electricity. It is the first grid-connected biogas plant in Africa and sells 50% of its power output to the national grid *(*www.tropicalpower.com).

1.6 Statement of the Research Problem

If fully exploited, biogas has the potential of providing up to 6% of global primary energy supply which is equivalent to a quarter of the current consumption of natural gas (Ladanai and Vinterbäck, 2009; WBA, 2013; GBA, 2016). However this is not yet the situation.Kenya through her Vision 2030 Agenda could use clean energy like biogas for environmental, social and economic benefits (Shell Foundation, 2007). Fossil fuels are major contributors to climate change and global warming but development and use of clean energy can mitigate negative effects of this phenomenon. Kiambu County hosts many farms capable of producing and benefiting from biogas production. However many demographic factors could be affecting effective production of biogas in Kiambu despite the county's high potential for its generation (Shell Foundation, 2007).

Under environmental governance, natural resources such as biogas are considered as "global public goods" meant for the well-being of mankind (Thalwitz, 2000; Launay *et al*., 2003; Kok *et al*., 2011). Thus biogas use needs to be promoted at all costs for the benefit of current and future generations. Governance is thus key in advocating sustainable utilization of biogas as a source of energy (Kotzé, 2006).

There are a number of legal and policy instruments in Kenya that were meant to provide guidance on exploitation of biogas technology such as the Sessional Paper Number 4 of 2004, the Energy Act of 2006 and the National Energy and Petroleum Policy of 2015. However these instruments have gaps that appear to impair adoption of biogas technology in Kiambu County. Through the three aforementioned documents the National government stated its desire to promote biogas as a clean form of energy but these instruments do not provide some processes and procedures through which this noble imitative can be implemented.

Details of how the technology could be productively exploited are missing, a good example being lack of policy on packaging biogas in cylinders and this had made it illegal for those who have adopted biogas to store it in this manner. With the exception of Gorge Farm Energy Park which sells its excess gas to the national grid, all adopters have to use whatever gas they generate and any surplus has to be flared, yet if there was clear policy, the gas could be packaged and sold thereby enhancing the use of clean energy as well as earn the investors some income. Policy is also lacking on piping the gas to consumers which is even more convenient and user-friendly compared to cylinders. These policy and legal shortcomings could have contributed to the low adoption rates of biogas in Kiambu County and Kenya as a whole despite many concerted efforts by various stakeholders.

Legislation that would ensure only quality bio-digesters are constructed and registration of artisans and contractors to keep away quacks is an avenue that can be explored in efforts to enhance adoption of biogas in Kenya. The Energy Act of 2006 and the Energy (Solar PV

Systems) Regulations of 2012 require technicians and contractors involved in the design and installation of solar equipment to be licensed by the Energy Regulatory Commission (ERC). Only qualified and experienced persons are eligible for registration and this has ensured standardization and quality of work in solar technology across the country. Similarly, licencing of electricians and electrical contractors is governed by the Electric Power (Electrical Installation Work) Rules (2006) with the ERC as the implanting agency Perhaps if this were to be replicated in the biogas sub-sector it would yield positive results.

Payment of carbon credits to adopters of biogas technology can encourage more people to embrace the technology. Carbon trading is an initiative with immense potential for social and economic empowerment yet a number of biogas adopters in Kiambu County were not getting carbon credits despite having been promised the same. The potential of carbon trading in facilitating adoption of biogas technology in Kiambu County can be partly actualized through enactment of an independent legislation dealing purposely with carbon emissions trading because this issue is not exhaustively addressed by the Energy Act of 2006 (CELP, 2013).

Having a specific Act of Parliament to deal with biogas technology can go a long way in giving the sub-sector the impetus it requires to spread across Kiambu County and Kenya as a whole. One reason why use of solar energy was increasing in Kenya is because of the Energy (Solar PV Systems) Regulations of 2012 which, among things require establishments that use more than 100 liters of hot water in a day to install solar water heating systems (ERC, 2012). This piece of legislation has provided the necessary guidance as far as promotion of solar energy is concerned.

Certain governance considerations for actors responsible for regulation of biogas in Kenya are therefore required to establish a deliberate effort to understand how governance influences uptake of biogas technology in order to clearly document why adoption of this technology is slow despite numerous campaigns for its adoption in Kenya (Githiomi *et al*., 2012; CIDP, 2013-2017).

As a high potential region, Kiambu can play a leading role towards production of biogas and thereby counteract adverse health, environmental and economic impacts associated with traditional biomass energy in the county and Kenya as a whole (Shell Foundation, 2007).

The study lays foundations for the basis of adoption of biogas technology to contribute towards achieving Sustainable Development Goals (SDGs) and most notably Goal Number 7 that focuses on access to affordable, reliable, sustainable and modern energy for all (UN, 2015).

1.7 Objectives of the Study

1.7.1 General Objective

To study factors determining adoption and management of biogas technology in Kiambu County.

1.7.2 Specific Objectives

i. To assess social-economic demographic factors that affect adoption of biogas technology in Kiambu County.
ii. To evaluate governance aspects on adoption of biogas technology in Kiambu County.

iii. To determine benefits of adopting biogas technology in Kiambu County.

1.8 Justification

Exploiting production of biogas can bring multiple benefits to the local communities (Shell Foundation, 2007).The study focused on providing a basis for an understanding on how to exploit biogas potential in Kiambu County so as to contribute to the community's energy supply. Kiambu was chosen because feedstock for production of biogas was available in plenty. Dairy farms such as Pascha, Browns Cheese, Vet Farm (belonging to the University of Nairobi) and Gatina; coffee farms like Kigutha, Ndumberi and Fairview; poultry farms like Muguku; numerous flower farms and horticultural plantations all produce vast amounts of substrate that is suitable for generation of biogas. Currently much of the feedstock remains unutilised. Besides the large scale farms, there is ample feedstock in the form of animal waste, human waste, industrial waste, municipal waste, sludge from slaughterhouses and various forms of agricultural residues.

Biogas will supplement the 5,000 + MW Project and the Last Mile Connectivity Project (LMCP) – these are initiatives of the Kenyan government whose aim is to increase generation and distribution of electricity countrywide. Enhanced generation of biogas will reduce the burden of relying on wood fuel with all its negative consequences on the environment (MOEP Strategic Plan, 2013-2017). Using biogas as an off-grid renewable energy source will help increase access to basic services that require energy and also boost energy access to households with limited income (Da Silva, 1980).

There is data deficit on biogas production in Kenya and this study hopes to help in this regard as one way of promoting adoption and utilisation of this form of energy in Kiambu County and Kenya as a whole (Fischer *et al*., 2010; ERC, 2012). It would therefore contribute to knowledge in green energy that is useful to stakeholders in the biogas sub-sector.

1.9 Scope and Limitations of the Study

Kiambu is a big county covering an area of 2,449.2 km^2 and it was not possible to visit all homesteads and institutions where biogas adoption has been implemented or there is potential for the same given limited time and funds. To overcome this, the researcher divided the county into East, West, North and South (an area that included Githunguri, Limuru, Lari and Ruiru sub-counties where the study was conducted) to ensure that no region was left out while collecting data from respondents. Again the 4 sub-counties cover a wide area and offer a fair representation of Kiambu County. Respondents were from different social-economic backgrounds which ensured divergent views were captured.

There could be other factors that have contributed to low adoption of biogas technology in Kiambu County that may not have been covered by this study. These may be considered for further studies by other scholars.

1.10 Conceptual Framework

The conceptual framework (Figure 1) for this study was based on the Diffusion of Innovation (DOI) Theory by Rogers, (1962) with modifications.

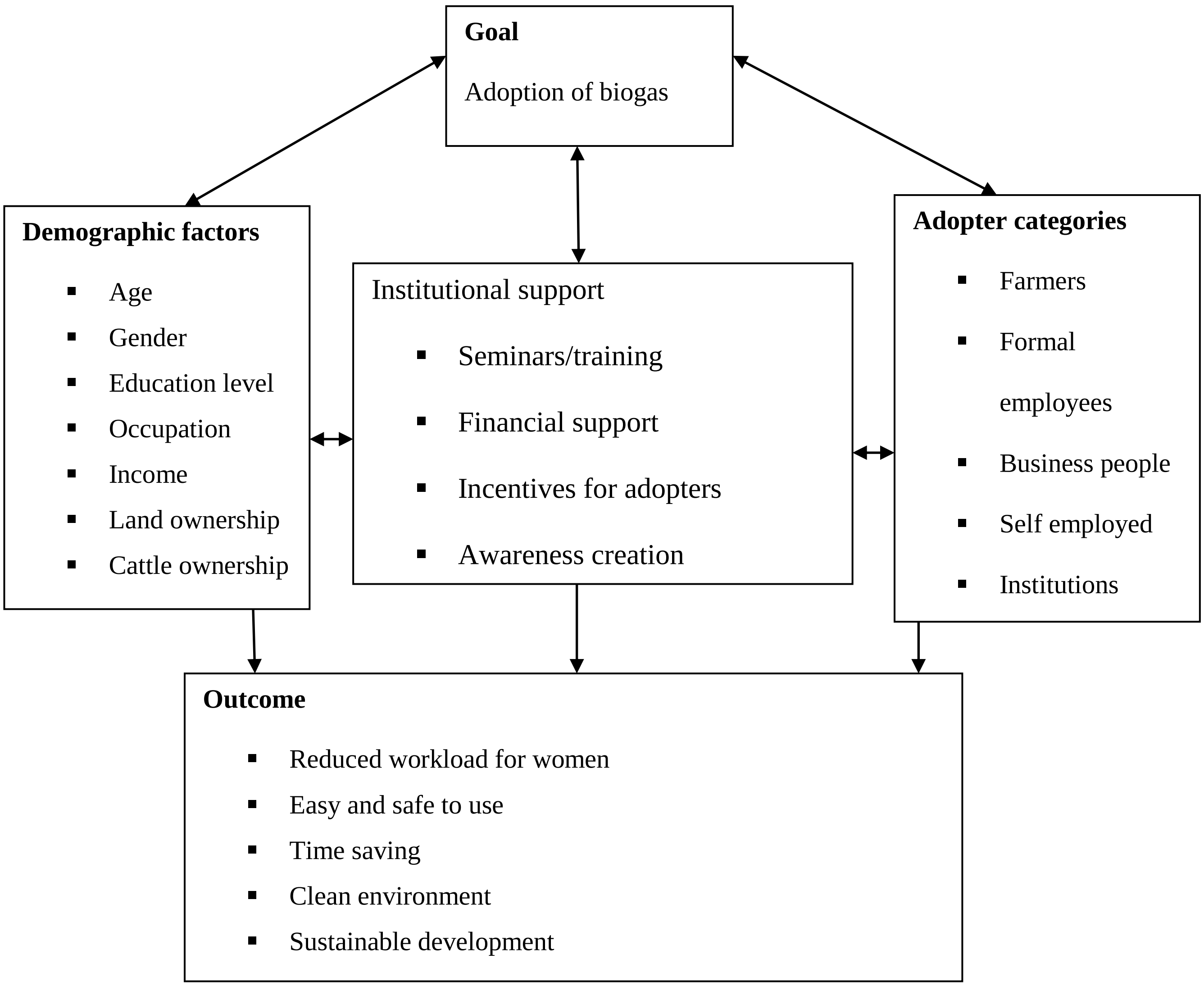

Figure 1: Conceptual Framework

The DOI Theory tried to explain how an idea or product becomes popular and diffuses through a given part of the population or social system (Rogers, 1962). A number of factors that can influence adoption of biogas technology are depicted and by creating awareness regarding the benefits of biogas as a clean form of energy, the technology can diffuse to a greater number of people living in Kiambu County. Awareness of the need for an innovation plays a significant role in an individual's decision to adopt new technology. The degree of adoption therefore varies for each segment of the society as explained in Figure 2.

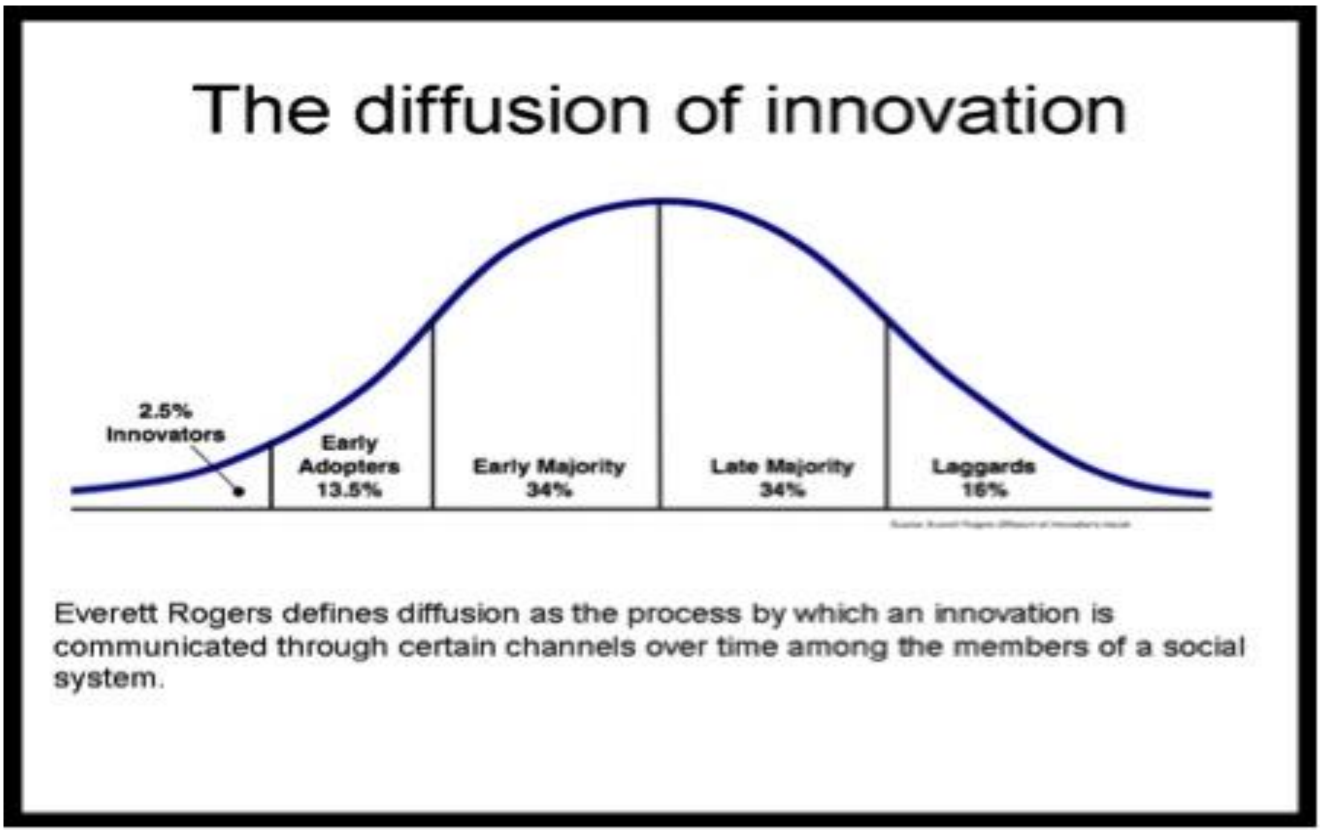

Figure 2: Illustration of diffusion of innovation in society.

For the case of Kiambu County the adopters could be farmers, business people and institutions. Potential adopters need to be sensitized about benefits of biogas technology such as saving time on cooking, no carbon emission hence a reduction of respiratory diseases caused by indoor air pollution (IAP), provision of light, less destruction of tree cover and a clean environment. This information can be availed by the National and County government plus other stakeholders through the electronic and print media, public meetings, policy papers, workshops, seminars, education and training. People tend to have different attitudes to new ideas which could delay their adoption of an otherwise useful technology and therefore there is need for proper sensitization.

Making clear the comparative advantage of using biogas as opposed to what is currently in use, especially wood fuel, would help in the adoption process. Potential adopters ought to be informed about the convenience that the new technology would offer and this can influence their shift to biogas.

1.11 Theoretical Framework

Three theories were adopted for use in undertaking this study, namely:

i. The Institutional Theory
ii. The Resource Based Theory
iii. Resource Dependence Theory

The Institutional Theory (IT) looks at the process through which structures that influence social behaviour are established. These could be laws, policies and practices and how they influence environmental strategies that are adopted by an organisation through some amount of pressure (Scott, 2004). Coercive pressure can also be brought against an organization by other institutions and even professional organizations all of which will have an impact on how the institution operates (Di Maggio and Powell, 1991).

Partly because of the push from different stakeholders who have an interest in a clean environment, sustainable, affordable and green energy supplies, the Government of Kenya as well as the County Government of Kiambu instituted measures aimed at promoting adoption and use of biogas. These include zero-rating the import duty and removal of Value Added Tax (VAT) on renewable energy equipment and accessories via the Finance Act No. 14 of 2015 as well as giving loans for installation of biogas plants on fair terms by financial institutions.

National and County laws and policies on energy have played a role in creating awareness regarding the importance of and influencing the adoption of biogas as a strategy of enhancing better environmental stewardship. They include:

1. Environmental Management and Coordination Act, 1999
2. Sessional Paper Number 4 on Energy, 2004
3. Energy Act, 2006
4. National Energy and Petroleum Policy, 2015
5. County Government of Kiambu Integrated Development Plan, 2013 – 2017
6. County Government of Kiambu Strategic Plan, 2013 – 2017
7. County Government of Kiambu, County Annual Development Plan (2016-2017)

The study looked at the impact of these instruments, among others, on adoption of biogas technology in Kiambu County.

The Resource Based Theory (RBT) considers resources as being vital to the performance of an organisation. Possession of strategic resources offers an organization a better opportunity to increase competitive advantage over its rivals which subsequently translates into increased profits (Wernerfelt, 1984; Barney, 1991). A resource is considered to be strategic if it is valuable, rare, difficult to imitate, and non-substitutable (Barney, 1991).

Energy is a strategic resource because it is critical to human survival. If Kenya were to have affordable and reliable supplies of energy, this would give the country competitive advantage over other nations by creating, among other benefits, an attractive environment for investors. Security of energy supply can play a significant role in enabling Kenya attain Middle Income Status as envisioned in the Government's Vision 2030 development blueprint as well as the SDGs. With plenty of resources compared to some regions in Kenya, Kiambu County has a sustainable competitive advantage of scaling up adoption and utilization of biogas.

The Resource Dependence Theory (RDT) looks at how external resources affect the behavior of an organization and its fundamental assumption is that actions of organizations are influenced by their dependence on critical and important resources (Nienhüser, 2008). Among external resources that are required for production of biogas include anaerobic bio-digesters, transport infrastructure and technical expertise which the proprietor may not have control over and this can affect the level of investment in the technology. External resources may be controlled by the National or County government, private companies and even individual persons. Therefore the success of biogas production will, to a certain extent, depend on the relationship between the proprietor and those in control of the external resources.

This chapter has looked briefly at Kenya's energy policies and the question of biogas in Kiambu County and noted that the area has the potential of enhancing production and utilization of biogas if existing resources are exploited to the full.

The resources are locally available and converting them into energy will help in sustainable management of various types of wastes leading to a clean environment. Enhanced production of biogas would increase access to clean energy by the community and help improve standards of living. This would reduce the level of energy poverty and help in bringing about environmental protection, social improvement and economic growth.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Biogas Production

Biogas is a mixture of gases produced through anaerobic decomposition of biodegradable substrate like manure, sewage, animal waste, municipal waste, green waste, plant material and energy crops particularly corn (Salihu and Alam, 2015). According to Kangmin and Ho (2006) biogas was used to warm bathing water as long ago as 10 BC in Assyria but the first plant to produce biogas from waste was constructed at the Matunga Leper Asylum in Bombay in 1859 where human waste was used to produce gas for lighting (Abbasi *et al*., 2012; Macharia, 2015). Efforts to produce biogas from manure were made in India in 1900 though it was not until 1937 when the first plant in this regard was commissioned. The technology was adopted in the United Kingdom in the 1890s where it was used to light street lamps in Exeter (Bond and Templeton, 2011).

By the end of the 19th century simple biogas digesters were being used in the coastal parts of southern China and from then onwards biogas technology has taken root and made great strides in Asia, with the leading countries in this regard being China, India and Nepal. By 2015 more than 100 million people in the Chinese countryside and another 4.83 million in India had access to biogas (Renewables, 2016). However in terms of advanced technology, Germany is the leader, with biogas and bio-methane providing 5.3% of the country’s electricity consumption in 2015 (Wiesheu 2016).

During the decomposition process, the micro-organisms transform biomass waste into biogas hence it is a sustainable way of converting organic waste into clean energy (Jørgensen, 2009; Salihu and Alam, 2015).The gas is produced in big containers known as bio-digesters and they are found in three main models: fixed dome (Figure 3), floating drum (Figure 4) and the balloon/tubular type (Figure 5). The fixed dome is made of bricks/blocks and cement and has an underground tank where the manure is deposited and an overflow chamber for collecting processed feedstock or slurry. As the anaerobic decomposition takes place, the gas is collected in the brick compartment. With changes and innovation in technology, fixed dome and floating drum bio-digesters made of polyethylene (PE) are now in use. The floating drum is a metallic structure that floats over the slurry; it floats higher as it gets filled with gas. The weight of the drum ensures that gas pressure remains at a constant level. For the polyethylene floating drum bio-digester, weights are put at the top to guarantee unvarying gas pressure. As for the balloon/plastic tubular type the bag is made of reinforced material where feedstock is deposited and the gas collects at the top; the balloon expands as it gets filled up with gas.

Unlike the other two, the fixed dome model can be constructed underground which offers it protection against the elements, deliberate or accidental damage as well as saving space. Despite their differences, bio-digesters have one common characteristic – they are anaerobic. The main compartments of a biogas plant are the reception tank, digester, gas holder and overflow tank (Karanja and Kiruiro, 2003; Kigozi *et al*., 2014). The design of the bio-digester will depend mainly on the type of substrate to be processed and level of operation (large or small scale). For optimum functioning, the plant must be put up by a skilled technician who understands biogas technology very well (Momanyi *et al*., 2016). In this way problems related to poor workmanship such as gas leakage, low gas pressure, reduced or lack of gas production during the cold season and cracks in the bio-digester will be avoided. In Sweden measures are taken to ensure that plants are installed as per the manufacturer's specifications and the technology is continually improved for best results (SEA, 2017). This can be emulated in Kiambu for optimum gas production.

A well-made biogas plant requires very minimal maintenance costs and can produce gas for between 15-20 years without any major breakdowns (Gebrezgabher, 2015). In an ideal situation, a $10m^3$ digester can supply sufficient gas for cooking and lighting to a family of five people for up to four hours per day. A pipe with control valves directs the gas from the bio-digester to the kitchen. Proper sizes of pipes must be used so as to increase gas pressure as it moves from the bio-digester to the point of use. High gas pressure generates intense heat thus increasing the efficiency and effectiveness of biogas technology because cooking and heating takes a shorter time.

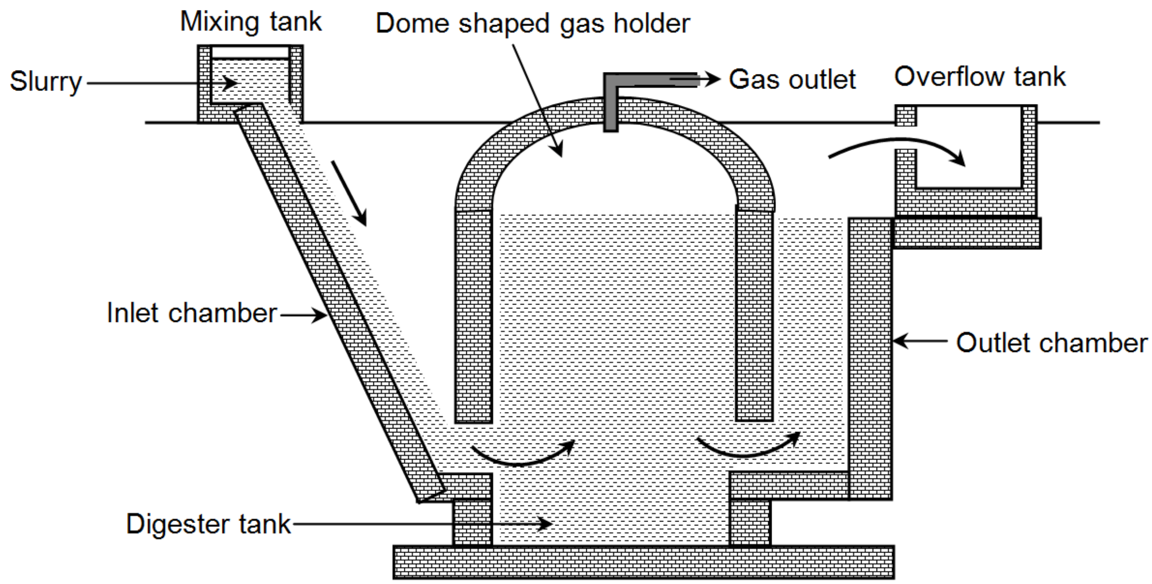

Figure 3: Drawing of a fixed dome bio-digester

Source: Google

Figure 4: A floating drum bio-digester made of polyethylene in Githunguri sub-county

Source: Field study, 2016/2017

Figure 5: Tubular bio-digester

Source: Flexi Biogas International, Karen, Nairobi

One of the critical aspects in the gas production process is what is fed to the animals: the type of food eaten by animals determines the calorific value of dung which subsequently dictates the quality of gas to be generated. Premium value feeds lead to good feedstock that guarantees gas of high quality and quantity. Chicken dung produces gas of premium quality because of its high calorific value and energy content; it is ideal for production of biogas compared to cow dung and one ton of chicken waste can generate approximately 200 m^3 of biogas (Fischer *et al*, 2010; Bijman, 2014).

Correspondingly, pig dung produces more gas than that from cattle with a kilo of the former producing up to 0.06 m^3 of biogas compared to 0.04 m^3 from the latter partly because pig waste is more solid compared to that of cattle (Aremu and Agarry 2012). However much of the biogas in Kiambu is produced from cattle dung because of their large numbers compared to other domestic animals (KNBS, 2010).

Ideally feedstock should be rich in energy and one that is easily digestible. When using liquid substrate like cattle dung, the correct ratio of water and feedstock must be observed to allow the fermentation process to take place flawlessly. Although the recommended ratio for mixing feedstock is 1 bucket of dung with 1 bucket of water, this also depends on the nature of the dung – wet dung requires less water for mixing compared to the thick variety. Proper mixing ensures uniformity of the substrate concentration and prevents solid deposition in the bio-digester leading to effective gas production (Mir *et al*., 2016; KeChrist *et al*., 2017).

To avoid process failure, feedstock must be sorted for any unwanted material before it is emptied into the bio-digester. This procedure is known as pre-treatment and is common where biogas is produced on a large scale (Achinas *et al*., 2017). For uninterrupted production of gas, feedstock must be put into the plant at regular intervals. Moderation needs to be observed when feeding the bio-digester: starving it leads to low gas production while an oversupply causes incomplete digestion and subsequent limited gas production. A good shed for storing feeds is important because among other things it helps to reduce the water content in food items like Napier grass as was noted during the study.

The health of animals is critical for production of biogas and the farmer must seek services of qualified veterinarians whenever livestock are sick or are showing signs of ill-health. Dung from ailing animals is not suitable for gas production; for example waste from recently de-wormed cows cannot be used for gas production until after 3-4 days because de-worming chemicals may alter the fermentation process in the bio-digester. Similarly dung from freshly sprayed animals cannot be used until after 7 days because the chemicals will introduce inhibitory factors in the bio-digester leading to its blockage as was explained by one farmer in Limuru sub-county during the study.

Biogas can also be produced from landfills where solid municipal waste (SMW) is piled up and compressed by the weight of additional garbage deposited above (Neves *et al*., 2009; Asgari *et al*., 2011) and waste water treatment plants (WWTPs) (Kayhanian and Rich, 1996; Wei, *et al*., 2008). While the decomposition process takes place, biogas is produced and when burnt, it reacts with oxygen and releases energy that is clean in nature. Production of biogas therefore poses minimal threats of environmental damage compared to fossil fuels (Trávníček *et al*., 2015).

Most bio-digesters in Kiambu were designed to process only one type of substrate (cattle dung), yet technology is available for co-digestion, hence most of the unused feedstock goes to waste. The advantage of co-digestion is that it maximises on the synergies of multiple substrates to produce gas of high quality compared to that generated through mono-digestion (Manou *et al*., 2008; Yohaness, 2010; Abdelhay *et al*., 2016). Kiambu County is blessed with a variety of resources that can be productively exploited for enhanced adoption of biogas and if co-digestion technology were to be applied, the amount of gas produced would go up significantly.

Proper management of the entire gas production system will guarantee its suitable functioning (Shell Foundation, 2007). Animals and their shed must be clean at all times to keep away flies and other insects as well as stench from animal waste while routine checks should be conducted to avoid clogging of the bio-digester (Mir *et al*., 2016). Clean water supply ought to be guaranteed while the bio-digester inlet should be securely covered to prevent unwanted material from getting into the plant, contain foul odours, maintain constant temperature, ensure the facility remains air-tight and finally collect gas.

After-sale service, maintenance and repairs have to be carried out when scheduled for optimum gas production and a long lifespan for the facility (Obwogi, 2014). Before using the gas it must pass through a filter to be cleaned of any impurities. Through desulfurization the filter removes sulphur and foul smell from the gas. Implementation of these management strategies would ensure optimal production of biogas together with its accompanying benefits because poor handling is one of the major causes of the biogas system failure (Muriuki, 2014).

Because of its continuous cycle of production and use, biogas is considered to be a renewable resource. Since there is no likelihood that generation of waste on which production of biogas is dependent will come to an end, creation and use of this form of energy will remain an uninterrupted cycle (Balat and Balat, 2009; Ošlaj, 2010).

2.2 Biogas Composition

The composition of biogas depends on such factors as the process design, type of substrate, how it has been prepared prior to gas production, retention period, conditions within the bio-digester such as temperature and pH as well as the presence of inhibitors (Šarapatka, 1994; Soranthia *et al*., 2012; Dobre *et al*., 2014). Biogas is made principally of methane (CH_4) at 50% -75% and carbon dioxide (CO_2) at 25% -50%, the remainder being trace gases like hydrogen sulfide (H_2S) and ammonia NH_3 (Salihu and Alam, 2015; Chaemchuen *et al*., 2016). However these figures vary depending on whether the gas was produced from bio-digesters, landfills or waste water treatment plants (Rasi, 2009).

Although methane is a greenhouse gas with adverse effects on the ozone layer and a global warming potential that is 21 times that of $C0_2$, this is destroyed during combustion and the result is a non-poisonous gas that does less harm to the environment (Jørgensen, 2009; Islam and Hossein, 2014). Similarly carbon dioxide is produced during combustion but the carbon is from organic material and does not contribute to climate change. Biogas therefore helps to convert harmful methane into useful clean energy and in this way it plays a critical role in minimizing GHG emissions that contribute to climate change and global warming while at the same time assisting in sustainable management of bio-waste (Bracmort, 2010; Islam and Hossein, 2014).

2.3 Anaerobic Digestion

Anaerobic digestion is the decomposition of organic matter that takes place in the absence of oxygen under the control of micro-organisms. The process can take place in bio-digesters, sediments of water bodies, the rumen of animals and landfills. Anaerobic digestion is influenced by external factors such as temperature, pH, trace nutrients, toxicants, type of substrate (biodegradability), organic loading rate, mixing ratio and design of the bio-digester (Cioabla *et al*., 2012; Lohani and Havukainen, 2017; KeChrist *et al*., 2017).

For gas production, the process takes place in the sealed, oxygen-free bio-digester and the result is biogas and bio-fertiliser commonly referred to as slurry. It is a safe and cost-effective method of disposing unavoidable organic waste as it has minimal negative impacts on the environment for as waste is converted into useful products, pollution of air, water and soil is minimized (Yilmaz and Demirer, 2008). In this way anaerobic digestion plays an important role in facilitating development of sustainable clean energy supply (Hublin, *et al*., 2014).

As noted earlier feedstock must be cleared of any non-biodegradable material that can interfere with the digestion process which takes about one month at approximately 55^{o}C before biogas is extracted (Debre *et al*., 2014). Low temperatures affect gas production and at 15^{0} C no gas may be produced. Anaerobic digestion is the most widespread method of treating municipal waste, notably sewage sludge as it reduces its final volume, minimizes the putrid smell and eliminates pathogens (Hornung *et al*., 2014). It is also ideal for treating human waste because excessive concentration of the same can lead to serious degradation of the ecosystem.

2.4 Sources of Biogas

Biogas can be generated from several sources such as animal waste, human waste, municipal waste, effluent from slaughter houses and agricultural residues (IUCN, 2015; Salihu and Alam, 2015). As indicated earlier, the principal feedstock for biogas production in Kiambu is cattle dung and the number of cattle in the county has been put at 120,056 (KNBS, 2010). Each cattle can produce about 30 kilograms of dung in a day which is the average amount required to produce biogas for approximately four hours, hence 120,056 cattle x 30 kgs = 3,601,680 kgs of cattle dung. This analysis shows that in one day alone, cattle in Kiambu County can generate biogas that would last for 900,420 hours – an amount that can significantly contribute to the county's energy mix, apart from economic, social and environmental benefits. There are no ranches in Kiambu County and most farmers practice zero grazing and this makes it easier to collect cattle dung for biogas production compared to animals that are reared on free range basis.

About 900 tons of solid municipal waste (SMW) is generated per day in Kiambu County (Kabogo, 2017) but much of it is not disposed of in a safe and responsible manner. Waste management in the County is a big challenge as only 2.6% of the population has access to waste disposal facilities (CIDP, 2013 – 2017) and this poses a serious threat to the environment as both solid and liquid waste are poorly disposed. Household and municipal waste can be utilized in production of clean energy and in the process a clean and green environment is guaranteed. One ton of municipal solid waste can generate up to 140 m^3 of biogas (Ghosh, 2016).Sensitization of people on proper handling of waste, enforcement of both National and County laws on refuse management as well as using waste to generate energy can help address the challenge posed by poor handling of waste.

The County Government of Kiambu has partnered with a Thika-based company known as Alternative Energy Systems Ltd (AESL) to help in addressing the issue of waste management. The company converts plastic waste into environment-friendly synthetic fuel oil that is used for operating hot water boilers. Fuel produced by the company is similar to industrial diesel oil and heavy fuel oil that is used in big institutions (AESL, 2017). This is a sustainable way of addressing the challenge of waste management in the County as it helps to alleviate ecosystem degradation, creates employment and brings about social improvement. According to AESL, 15% of waste generated in Kiambu is plastic and hence the rest can be used in generating biogas and this will ensure productive utilization of waste. Failure to properly manage waste in Kiambu is a big threat to man and the environment yet the same can be used in production of clean energy that is affordable, reliable and sustainable.

Commercial poultry farming is well developed in Kiambu County with Nairobi providing a ready market for eggs and chicken. Thousands of kilos of waste produced by chicken are a good source of biogas, more so because of the high calorific value of chicken waste compared to cattle dung. Effluent from slaughterhouses is also appropriate for generation of biogas as evidenced by the Dagoretti Slaughterhouse in Kikuyu sub-county and Keekonyokie Biogas Company at Kiserian Town in Kajiado County. As noted during the study, about 660 liters of blood and 850 kg of dung are produced at Keekonyokie from the 600 animals that are slaughtered on a daily basis out of which 60 m^3 of gas is produced per day. This is the only firm in Kenya with the capacity to bottle biogas.

There are a number of slaughterhouses in Kiambu County whose effluent can be used in generation of biogas and in the process ensure good environmental management as well as uplifting the social-economic status of the people (Thaiya, 2008). It is only at Dagoretti slaughterhouse where effluent from the slaughterhouse is used in producing biogas.

Although it is found wherever people have settled, human waste is rarely used to generate energy in Kiambu, partly due to cultural and attitudinal reasons. In the urban centres of the county, human waste from the many residential areas, institutions and business premises could be used to generate energy. It was only in a few schools where human waste is used to generate biogas and this venture had improved hygiene conditions as well as drastically reduced the institutions' energy bill.Institutions have the comparative advantage of generating a large volume of human waste that can be used to produce biogas compared to individual homesteads. When human waste is used for energy production, its negative impact on the environment is significantly managed (Ali *et al*., 2013; Ragattieri *et al*., 2018). However this is hampered by lack of a modern sewage system in Kiambu County that would facilitate conversion of human waste into biogas (CIDP, 2013 – 2017; CGK, 2017).

Kiambu is one of the major coffee growing areas of Kenya and waste such as pulp and husks can be used to generate clean energy (Mwakesi, 2014). Coffee pulp is a suitable substrate in the anaerobic digestion process (Steiner, 2011; Corro *et al*., 2014; Meng *et al*, 2016) and the huge amount of this product that is released by factories in Kiambu is a good source of biogas generation. There are five major coffee factories in Kiambu and if their pulp and husks can be harnessed for production of biogas it would also be a good strategy of sustainable environmental management because sometimes the waste is carelessly disposed (Ulsido *et al*., 2016; Steiner, 2011). Indeed, the pioneer biogas plants that were established by white settlers and those initiated by the German Agency for Technical Corporation (GTZ) in Kenya in the mid 1950s used coffee pulp as feedstock. Countrywide, approximately 80, 189, 500 KW of electricity can be generated from coffee pulp (Fischer *et al*., 2010).

Kiambu County is also famous for growing cut flowers for export but only 20% of the plant is commercially marketable while the rest is waste that is suitable for generation of biogas. It has been estimated that from floriculture alone, the county can generate up to 16,083 KW of electricity which would be a significant contribution to its energy needs (Updated Rural Electrification Master Plan, 2009).Fruits are grown on a large scale in the county and their waste provides another source of feedstock for bio-digesters.

Conversion of refuse into energy is an example of an integrated waste management strategy as it would provide multiple environmental benefits: apart from producing renewable energy, the environment is kept clean and employment created in the process (Tengeya, 2014). Similarly, when waste that is potentially harmful to human health is properly managed, this leads to fewer cases of disease outbreaks.

The limited number of resources that are used to produce biogas in Kiambu has affected its rate of diffusion and this is despite the fact that many other useful material go to waste (Gitonga, 1997; Burkad, 2009). If all available resources could be utilized in producing biogas it would accelerate its rate of adoption and diffusion.It is therefore important for Kiambu residents to be sensitized about the various types of feedstock available in the county that can be used to generate biogas for this would be one way of ensuring optimal exploitation of biogas potential. Reliance on cattle dung alone had limited production of biogas but diversification of feedstock has the potential of increasing production of this form of renewable energy. Maximum utilisation of available resources to produce biogas can turn Kiambu into a model county as far as green energy is concerned.

2.5 Digested Substrate

Other than biogas, slurry or digested substrate is generated as a by-product of the decomposition process. Knowledge about slurry is relatively limited because much of available literature focuses on biogas as the main product of the decomposition process hence even some adopters are not aware of its usefulness (Groot and Bogdanski, 2013). Ignorance of multiple benefits of slurry has partially contributed to the low adoption of biogas technology in Kiambu but adopters who are aware of its benefits prefer it due to its rich nutrient content that facilitates increased crop production per unit area (Gitonga, 1997; Heegde and Sonder, 2007). Use of slurry can raise yields among farmers who then save money that would have been spent on chemical fertilizers that comprise the additional disadvantage of contaminating soil and ground water resources.

Reduction in use of chemical fertilizers also minimizes carbon emissions that would have been generated by factories and vehicles in the course of production and transportation, respectively.

Slurry is also used as fish food and this had encouraged fish farming in Kiambu County. The County Government of Kiambu has been involved in promotion of fish farming as one strategy of raising nutritional levels of the people as well as providing them with a new revenue stream (CGK, 2018). Previously fish farming was virtually non-existent in the county but sensitization on the usefulness of slurry as a key ingredient in fish diet had encouraged many people to engage in it as a revenue generating stream (Ngwili, 2014). Furthermore slurry can be utilized as pesticide and fungicide where it was found that it offered better results in pest control compared to the commercial varieties (Groot and Bogdanski, 2013). By reducing the growth of weeds, slurry saves farmers money that would have been spent on weeding or purchasing chemicals to control unwanted growths on farms. Avoiding use of commercial pesticides also saves the soil and water from chemical contamination.

Slurry can be processed then sold in liquid or solid form to earn farmers additional revenue (Groot and Bogdanski, 2013; SNV, 2018). As a strategic waste management solution, commercial disposal of slurry helps in keeping the environment clean and ties well with objectives of Kiambu County's Fiscal Strategy Paper for 2016 of providing support to middle and small scale farmers in order to, among other things, help them earn an income and attain food security (CKG, 2016).

2.6Biogas Utilization

As a high grade fuel, biogas can be put to various uses like cooking, heating, lighting and powering engines (Home Biogas, 2017; Mbali *et al*., 2018). In Kiambu County the gas is used mainly for cooking and heating with a few exceptions where it is utilised for lighting and powering stationery engines. In homesteads and institutions where biogas was adopted, use of wood fuel has been replaced with it leading to a clean environment. Difficulties related to use of wood fuel such as respiratory diseases, eye irritation, smoke inhalation, high cost and lack of security of supply came to an end with the adoption of biogas.

Whereas in the developing countries biogas is used principally for cooking, heating, lighting and powering electrical appliances, in the developed world this form of energy is used mainly for production of electricity for industries and in the transport sector (Neves *et al*., 2009; WBA, 2013; Feroldi *et al*., 2016; Larsson *et al*., 2016; Scandinavian Biogas, 2016).

In the Swedish city of Linköping most vehicles run on biogas and the city is home to the world's first biogas-powered train (Mayer, 2012). Growing interest in using biogas as vehicle fuel has been influenced by challenges of fossil fuels and environmental concerns, notably climate change caused by GHG emissions. For biogas to be used in vehicles it is converted into compressed natural gas (CNG) and because it is a carbon-neutral bio-fuel, it does not emit poisonous fumes like petrol or diesel (Rasi, 2009). Compared with other fuels, CNG is much safer to use and in case of spillage there is no likelihood of an explosion.

Biogas is also ideal for warming water for bathing and room heating particularly in cold places like Kiambu where temperatures usually drop to as low as 7^0 C between June and July. In this way, cold related ailments can be avoided. Poultry incubators and hatcheries can also be warmed using biogas instead of charcoal, kerosene or expensive and unreliable electricity from the national grid (Bernd and Stefan, 2013). With a guaranteed continual supply, biogas is a viable option in terms of provision of energy because of its clean, affordable and sustainable nature.

2.7Governance of Biogas Production

Most biogas plants in Kiambu are privately owned by farmers who installed them in their own individual capacity. Institutions such as schools had installed bio-digesters mainly to reduce their energy bills. Although biogas users' associations were important in the green energy sub- sector, very few were in existence in Kiambu County and membership was equally low. Experience from elsewhere shows that through biogas users' associations, members share ideas of mutual interest such as networking and benchmarking on best practices, research and development on emerging issues in this sub sector as well influencing policy on biogas (BAG, 2017; EBA 2017). Such experiences can be useful in Kiambu County where the associations could also lobby for the government, donor agencies and other stakeholders to increase support and facilitation in adoption of biogas technology.

The governance aspect is important as it involves critical issues that have a strong bearing on adoption of biogas technology in the area of study. The county government is involved as a stakeholder in formulation and implementation of legal and regulatory frameworks, creating awareness of green energy and formation of biogas users' associations, among others. The

National and County governments were in support of promoting use of biogas through legal and policy instruments but this was yet to be fully felt at the grass root level. For example Sessional Paper Number 4 of 2004 explicitly pledged to promote domestic and institutional biogas technology, among other renewable energy sources but its impact may take long to be felt partly because no mechanism of how this facilitation was going to be implemented is spelt out.

The government is an important stakeholder in matters of green energy and there are several strategies that can be used in enhancing diffusion of biogas. Official policies on biogas can be spread and implemented at different levels of government using respective agencies (Raha *et al.*, 2014). In Kenya such multiple institutional arrangements can be at the national, county, sub-county and ward levels and this will help accelerate knowledge about biogas technology.

Adoption of legislative reforms that are geared towards increasing adoption of biogas, facilitation of research and development, offering financial incentives, availing subsidies and supporting private sector initiatives are other avenues through which the government can help in adoption of biogas technology in Kiambu County (Sawhney, 2013; Muvhiiwa *et al.*, 2017). Involvement of multiple stakeholders in governance aspects has the potential of raising the amount of gas produced thereby paving the way for increased access to clean energy especially to those who are in off-grid regions. This devolution of energy supplies has the potential of raising levels of adoption mainly because it is dependent on locally available resources.

Realisation of the importance of green energy across the globe has motivated a number of countries to form ministries that are responsible for renewable energy. This is informed by the fact that political and economic variables have a significant role to play in the move towards universal access to clean energy (Raha *et al*., 2014). Where such government initiatives have been implemented, an increase in diffusion levels of renewable energy has been noted (Gold and Seuring, 2010; KPMG 2015). One advantage of such policies is that an increase in generation of clean energy simultaneously leads to reduction in carbon emissions (Sawhney, 2013).

2.7.1 A Continuum of Governance Structures

There are a number of structures in the biogas supply chain ranging from legal instruments, production/manufacturing, distribution, retailing, installation and utilisation. In addition there are companies that handle biogas equipment with some importing the merchandise while others are locally manufactured. From manufacturers the items are transported to retailers for sale to clients. Ideally clients should seek professional advice to enable them make informed decisions when buying the equipment which should also be installed by a qualified technician (Ghimire, 2009; Mwenja, 2011). During installation the right type of sand must be used in constructing the chamber for fixed dome bio-digesters to make it air-tight so that there is no leakage of gas. Failure to consult on the suitability of the equipment and use of unqualified persons to put up bio-digesters had led to poor performance and eventual breakdown of some plants in Kiambu County.

Government and non-governmental organisations, co-operative societies and community based organisations (CBOs) form part of the wider governance structure in terms of licencing (regulatory), sensitization, financial and technical support as well as community mobilisation

(Lybæk, 2013). There was need for coordination of activities of these structures to ensure that they all play their respective roles that would lead to the optimal goal of up scaling adoption and utilisation of biogas in Kiambu County.

2.7.2 The Most Appropriate Governance Structures

The key goal of governance structures is enhanced adoption and use of biogas technology in Kiambu County for the attainment of sustainable development and structures that would enable this to happen at a reasonable cost will be the most appropriate. As a key player in promotion of green energy, the government has the responsibility of initiating measures that can trigger increased adoption of biogas such as tax reductions, subsidizing the cost of biogas equipment and a general improvement of the local infrastructure. By using legal instruments as governance structures to initiate these incentives, it was possible for biogas adoption levels to go up because where such measures are in force, uptake of biogas is phenomenal (EU, 2016).

The Central American nation of Costa Rica has generous subsidies for materials used in putting up green energy facilities and by 2012, the country was generating 90.9% of its energy from renewable sources, mainly hydroelectric, geothermal and wind and plans are underway to make the nation rely on 100% green energy by 2021 (WWF, 2014; KPMG Report, 2015). In Nepal, the government provides subsidies that meet up to 40% of the cost of a biogas plant and this had led to high levels adoption of this technology. Today Nepal has been recognised globally as the country with the best practices in the biogas sub-sector (Karki *et al*., 2015).

Financial and technical support is another governance structure that can be used to support those interested in adopting or have already adopted biogas technology. Offering loans with friendly repayment terms and equipping the community with skills in biogas technology is a cost effective strategy in promoting adoption of biogas (Gitonga, 1997; Shell Foundation, 2007). One avenue that can be pursued by interested stakeholders in this regard is the Strengthening programme that commenced in 2014 with support from the British government through its International Climate Fund (ICF) commitment. The main objective of the programme in Kenya is to help the country cope with negative impacts of climate change and scale up access to clean energy and in the process help improve people's standards of living (FICCF, 2014).

The challenge for some households could be lack of collateral against which loans for facilitating adoption can be taken (Momanyi *et al*., 2016). By using the reward and punishment strategy, homes and institutions that adopt biogas could be targeted and incentivized with carbon credits and other non-financial payments while those that do not are sanctioned (Xiao *et al*., 2016).

2.7.3 Role of Public Sector

The National and County governments are the principal public sector players in biogas matters and this is done through their respective agencies. For the National government, the Ministry of Energy and Petroleum and the Energy Regulatory Commission (ERC) are at the forefront of promoting biogas usage while at the County level it is the Department of Water, Environment, Energy and Natural Resources. Through zero-rating the import duty and removal of VAT on renewable energy equipment and accessories via the Finance Act No. 14 of 2015, the government hoped to enhance adoption and use of biogas (NCCAP, 2013-2017). In 2017 the government began a drive to construct biogas plants in public secondary schools to save the institutions heavy energy bills and the ecosystem from degradation.

The County Government of Kiambu has partnered with private sector institutions and Non-Governmental Organisations (NGOs) like Visionary Empowerment Programme (VEP) to sensitize the local community and provide support to those who wish to invest in biogas technology (VEP, 2017). For wider reach of this initiative women and youth groups have been targeted so that bio-digesters can be installed in their premises for domestic and commercial purposes as one way of improving their livelihoods.

2.7.4 Role of Private Sector

Non-governmental organisations, financial institutions and farmers' cooperative societies are among the key private sector establishments that are championing use of biogas as a clean and sustainable form of energy in Kiambu. There are 38 registered NGOs operating in the County (CIDP, 2013 – 2017) and in terms of promotion of biogas their entry point is usually creating awareness, micro-finance and technical support for those who have interest in the technology. The NGOs supplement government efforts geared towards increasing access to clean forms of energy by as many people as possible, especially those outside the national grid.

Capacity building is conducted through offering technical skills to artisans, creating awareness within the community on benefits of using biogas and availing loans on friendly terms.

Organisations like Githunguri Dairy and Community Savings and Credit Corporative Society Limited (GDC SACCO), VEP and GTZ not only offer loans but also sensitize the community on benefits of adopting biogas (Ngigi, 2009). Coffee and tea co-operative societies also provide credit to farmers to enable them adopt technologies like biogas (Kiambu County Strategic Plan, 2013-2017).

The Kenya National Federation of Agricultural Producers (KENFAP) supported farmers in areas like Limuru by giving 80% subsidy to those who were interested in biogas technology as was found out during the study. With the help of donor agencies, the Kenya National Domestic Biogas Implementation Programme (KENDBIP) had among its targets realization of Millennium Development Goals (MDGs) through promotion of the use of biogas (KENAFF, 2016). Through KENDBIP interested farmers were given a subsidy of Kshs 25,000 which was equivalent to 30% of the cost of installing a fixed dome biogas plant but this was discontinued at the end of Phase 1of the pilot project in 2013 (Porras *et al*., 2015; Karki*et al.*, 2015) leading to a slow-down in uptake of biogas technology. Revival of such an initiative would contribute to raising the adoption level of biogas use.

In Limuru sub-county some adopters have formed the Limuru Biogas Users' Association through which they share matters of mutual interest to them. Women groups had also helped members interested in biogas technology get financial, technical and advisory support from relevant institutions. The Visionary Empowerment Programme has been instrumental in providing micro-finance solutions and expert advice on biogas technology to men, youth and women groups in

Kiambu County (VEP, 2017).On the whole NGOs have made more contribution in the promotion of biogas technology in Kiambu compared to the National or County government input. The impact of these organisations' efforts is vindicated by the fact that most of the biogas plants in Kiambu were put up with private sector support. All adopters stated that they had not seen the National or County government's solid intervention in promotion of biogas which, to them, would have greatly helped in adoption of this technology.

Private sector initiatives in green energy need support of the government so as to make their efforts more fruitful (Galai, 2003; OECD, 2014). At Keekonyokie slaughterhouse in Kiserian Town of Kajiado County, an initiative to package biogas in cylinders is yet to be approved by the government because there was no policy on bottling biogas. A total of 60 m^3 of biogas is produced on a daily basis but only a very small percentage is utilized for lighting the facility. Excess gas is flared yet if proper facilitation was offered by the government the same biogas would have gone a long way in improving the livelihoods of the local community and beyond.
Hopefully once the relevant regulatory requirements are put in place, such noble initiatives will get official recognition and support so that they can effectively play their role in sustainable development.Deliberate interventions at national and county levels can help in the shift from a carbon-intensive economy to a sustainable energy system of clean, efficient, affordable and renewable energy. National policies and political leadership have the potential of driving wider acceptance of renewable energy technologies (MOEP, 2004; GK, 2007; NEPP, 2015).
In South Asian countries like India, Nepal and Pakistan, official support to farmers who want to embrace biogas technology is evident down to the grassroots level. For example in Faisalabad

District in Punjab Province of Pakistan, the Punjab Rural Support Program (PRSP) avails support in the form of information, funding and technical knowledge on how to install biogas plants (Iqbal *et al*., 2013) and this had helped in spreading adoption of biogas technology in that country. A radical shift in policy therefore would aid in the realization of a biogas revolution in Kiambu and Kenya at large because resources for the same are available.

2.7.5 Economic and Institutional Factors

Market conditions are usually determined by forces of supply and demand, and ideally even without external intervention, the market ought to regulate itself (Beyers, 2017). Low demand for biogas technology can lead to a drop in price of relevant accessories and less profits for traders who may eventually cease stocking necessary equipment. This could also discourage acquisition of skills in biogas technology yet it is critical in its diffusion.

Due to a number of factors, the initial cost of installing a bio-digester is considered to be quite high by many people and this can have a negative impact on the level of adoption. The supply and demand of goods and services can equally be manipulated to the advantage of a selected few through such means as creating artificial shortages that lead to price increase or deliberate oversupply that disrupts normal trade through price drops (Gold and Seuring, 2010; AFM, 2017). Shortages can lead to price increases that eventually hamper diffusion of new technology. Therefore market failures can have a negative impact on the potential of up scaling adoption and use of biogas.

2.7.6 Asset Specificity

Bio-digesters are specifically designed to produce biogas and cannot be used for any other purpose. Their usefulness is therefore determined by the efficiency and effectiveness with which they perform this function failure of which they become worthless. Asset specificity can affect the re-sale value of an item thereby forcing an investor to sell it at a very low price, give it away for free or even abandon it. A high degree of asset specificity is directly proportional to its low resale value (Quinn, 2010). Biogas plants are also site-specific because they cannot just be installed anywhere and this too affects their resale value particularly after decommissioning.

Virtually all biogas plants surveyed in Kiambu were specifically made to generate gas from cattle dung and have no capacity for co-digestion of different feedstock. This limits gas production while the unused feedstock goes to waste. Introduction of bio-digesters with the capacity for co-digestion would increase the amount of gas generated in the County (Bank *et al.*, 2011). Similarly there is limitation on utilisation of biogas in Kiambu County since much of it is used for cooking and heating yet it can be deployed for multiple functions.

2.7.7 Uncertainty

A number of factors can create a state of uncertainty in the biogas sub-sector. Unpredictable weather conditions can have adverse effects on biogas production because, for example, adopters in Kiambu use cattle dung as the main feedstock. During the dry season fodder is scarce and expensive and water can be a challenge yet cattle need a balanced diet in sufficient quantities in order to produce enough dung for gas generation (Yohaness, 2010; CGK, 2017). In extreme cases cattle succumb to death due to effects of drought or floods leading to disruptions in gas production. Climate change challenges that are being experienced today are partly caused by the type of energy in use and hence there is need to enhance adoption of clean energy like biogas. The likely loss of cattle to ailments such as foot and mouth, lumpy skin disease and anthrax may cause uncertainty in production of biogas thereby discouraging potential adopters.

Government measures that can lead to increase in taxes and prices of animal feeds, transport, veterinary services and other factors of production can make generation of biogas costly which may force some people to prefer wood and fossil fuels as a viable option regardless of consequences to the environment (Mittal, *et al*., 2018). Even where policies may appear favourable to investors, uncertainty sets in when people are sceptical about their sustainability.

Technological advances that bring about different designs of bio-digesters can create investor uncertainty of not knowing the right type of plant to go for (Sok, 2012). This can be overcome if the County Government of Kiambu and other relevant stakeholders could facilitate provision of correct information on new technologies to potential adopters and those who want to upgrade their biogas infrastructure so that they can make informed decisions.

2.7.8 Government Policy

The official policy of both the National and County governments is to promote use of biogas as a clean and sustainable form of energy as envisaged in their respective legal, policy and regulatory instruments such as: the Sessional Paper No. 4 on Energy, 2004; The Energy Act, 2006; National

Energy and Petroleum Policy, 2015; the Sustainable Energy for All (SE4All) initiative; County Integrated Development Plan, 2013-2017and the County Annual Development Plan, 2016-2017. This has been informed by the realization that continual use of wood fuel in Kiambu and Kenya at large by majority of the population was no longer sustainable due to the serious negative impacts on man and the environment.

The Feed-in-Tariff (FiT) policy of 2012 was a major government intervention in promotion of green energy and its objective was to encourage generation of grid-connected electricity from renewable energy resources, including biogas by offering favourable returns to investors (Fischer*et al*., 2010; MOEP-SE4All, 2016). Through this policy, the government sets high payments to private investors in renewable energy with figures remaining fixed for 20 years.

In 2010 the government set up the Green Energy Task Force (GETF) with the overall mandate of expanding generation of green energy (MOEP, 2010).Another major policy intervention was removal of VAT on plastic bio-digesters in 2015 as a measure of enhancing adoption of this technology (Finance Act, 2015). Concerted and continued policy support of renewable energy initiatives is a significant contributor to the development of this sub-sector as seen from experiences in other countries (KPMG, 2015). Establishment of the Energy Regulatory Commission (ERC) in 2006 as the sole government agency to deal with renewable energy and appointment in 2018 of a Principal Secretary to be specifically in charge of renewable energy were other steps by the government to show its seriousness in the development of clean energy (Osawa, 2011).

So far, the most elaborate policy document in this aspect would have been the Energy Bill 2015, which had recommended fundamental interventions in the renewable energy sub-sector. Among other things, the Bill called for the establishment of the Rural Electrification and Renewable Energy Corporation, whose mandate would have included setting up of energy centres in the counties, conducting feasibility studies and maintaining data on renewable energy. This would have been the first time that the government had set up an agency whose specific mandate is renewable energy but unfortunately the Bill did not get Presidential Assent to become an Act of Parliament

A number of initiatives have been established through which the government hoped to attain green energy goals within specified time-frames. They include the Last Mile Connectivity Project which aimed at connecting over 70% of the population to the national grid by 2017 (this was not achieved) and universal access to clean energy by 2020 (MOEP, 2018). Through such initiatives the government has made attempts to promote generation and use of green energy as one of the strategies of sustainable development with a view to ensuring good environmental practices. Perhaps a better strategy would be to set up targets of when a given percentage of Kenya's energy consumption would be from renewable resources. Some countries have set targets of when a particular percentage of their energy consumption has to be derived from renewable resources and this gave them the impetus to work towards that goal. For example in January 2007, the European Union came up with the Renewable Energy Road Map (RERM) that required all member states to produce 20% of their energy consumption from renewable resources by the year 2020 (EU, 2007). The RERM had the twin objective of enhancing security of supply for members as well as reducing GHG emissions by the set deadline.

The government is yet to allow packing of biogas in cylinders and any excess gas that is not utilized usually goes to waste. Allowing packaging of biogas would increase access to clean energy, particularly for the low income earners because it is cheaper than LPG (Soranthia *et al*., 2012). In this way adopters will earn extra income from their clean energy investment. Promotion of the use of biogas needs more concerted efforts by all stakeholders for the effects to be felt. Positive government policies touching on issues such as tax rebates, incentives to adopters and upgrading of infrastructure can instigate diffusion of biogas technology (KIPPRA, 2010).

In Kenya the government could take advantage of support offered by the African Biogas Partnership Program (ABPP) to spread the technology across the country (Mulinda *et al*., 2013). Policy interventions such as provision of financial assistance, water supply, good roads and veterinary services would make adoption of biogas easier and viable. Enhanced official support at the national and county level can go a long way in unlocking biogas potential in Kiambu that would enable residents reap full benefits associated with green energy.

2.7.9 Other Institutional Factors

There are different opinions about the best type of bio-digester among the three, ie fixed dome, floating drum and the balloon/tubular model. The main argument has been the efficiency and effectiveness of gas production, durability and ease of use (Karanja and Kiruiri, 2003; Shell Foundation, 2007; Ochieng, 2010; Muriuki, 2014). The first two are said to be more durable than the balloon type because of the nature of material used in their construction.

There has also been no agreement on the best way to store biogas once authorisation is granted by the ERC with some stakeholders preferring it to be kept in huge tanks from where it can be piped to consumers instead of using small cylinders for individual clients. Divergent opinions on storage have negatively affected the growth of the biogas sub-sector in Kiambu County because the inability of adopters to bottle and sell gas due to government restrictions had discouraged potential adopters.

2.7.10 Historical Factors in Kenya

The history of biogas in Kenya goes back to the 1950s when it was introduced by white settler farmers like Tim Hutchinson who was producing the gas in 1954 (Gitonga, 1997; Shell Foundation, 2007; Ndereba, 2013; Obwogi, 2014). Promotion of the technology gained momentum in the 1980s and by 1990, about 300 biogas plants were put up in the country mainly through efforts of the Special Energy Programme (SEP) – Kenya and the then Ministry of Energy and Regional Development. This came about following a SEP survey in 1984 which revealed that of the 160 biogas plants in Kenya at the time only 25% were in operation, but because of the benefits of renewable energy that were becoming more evident, the government with the support of GTZ started country-wide promotion of adoption of biogas (Mugo and Gathui, 2010).

Biogas technology in Kenya received additional assistance through the Netherlands-supported KENDBIP and is now being promoted as a sustainable energy source. Under KENDBIP the target was to install 8,000 domestic biogas plants with a capacity of between 6 m^3 – 12 m^3 by 2013 (KENAFF, 2016). The overall objective of KENDBIP was achievement of the MDGs through development of biogas as a sustainable source of energy in the country.

2.7.11 Lack of awareness

Lack of awareness regarding biogas technology had hampered its possible enhanced adoption in the country (Fischer *et al*., 2010; Ndereba, 2013; Obwogi, 2014). Despite its usefulness to man and the environment, many people are not sensitized about benefits of biogas compared to fossil based sources of energy and coupled with the drudgery of producing biogas, this had even made some of them develop a negative attitude towards it. For example handling animal waste in the process of producing biogas had made a number of people to develop a negative attitude towards the technology (Moorman, 2012). To them it is demeaning and they prefer alternative energy that does not soil their hands.

2.7.12 High Installation Cost

The initial cost of installing bio-digesters is relatively high for many people and this has had a negative impact on adoption levels. The price of digesters ranged from Kshs 50,000 to over Kshs 2 million depending on the type, size and material used in construction and this was deemed to be costly by the respondents given other competing needs that they have (Ndereba, 2013; Muriuki, 2014; Momanyi *et al*., 2016).

2.7.13 Alternative Sources of Energy

Availability of alternative sources of energy had made some people hesitant to change to biogas because being a seemingly new technology, they were not sure of its sustainability owing partly to lack of sensitization. Because of the long tradition of using alternative sources, some people were finding it difficult to shift to an unknown mode against which some had even developed a negative attitude. As is normally the case with new technology, people tend to take time to adopt it as illustrated by the Technology Acceptance Model (TAM) of Davis (1989). This theory states that people will adapt to new technology if they are convinced about its perceived usefulness (PU) and perceived ease of use (PEOU), in the absence of which they tend to refrain from adoption.

2.7.14 Availability of Technical Skills

Technical knowledge was critical in the spread of biogas technology and where these skills were utilised, there was a corresponding higher rate of adoption (Ghimire, 2009; Wamwea, 2017). Kiambu County faces a serious shortage of skilled artisans in biogas technology and this had affected the degree and pace of adoption. Indeed the researcher came across only four qualified technicians whose work was evident in homesteads and institutions where they had installed the plants. The owners confirmed that their plants had not broken down since installation by the skilled technicians, some having been put up more than ten years ago. Virtually all the failed plants were constructed by people who had little or no professional training in the technology. Compared to established and credible companies, most independent artisans gave no guarantee for their work and it was not easy to trace some of them once they had installed a biogas plant.

There is a strong relationship between availability of skilled technicians and successful adoption of biogas technology (Momanyi *et al*., 2016) and the Resource Dependence Theory of Nienhüser (2008) states that the success of a venture depends on the level of dependence of the organisation in question on critical resources, in this case the technical expertise. If the artisans are skilled there will be a higher level of performance of bio-digesters that they install compared to those put up by unskilled or semi-skilled people and this was likely to persuade many people to adopt biogas technology.

According to Gitonga (1997), acceptability of biogas technology was noted in areas where bio-digesters had performed well and the contrary was the case where the failure rate of the plants was high. The success of biogas technology is therefore determined by the degree of satisfaction that users accrue from the performance of the plants (Karki *et al*., 2015). When biogas plants function well, they bring multiple benefits to users in terms of environmental, social and economic dimensions. It is therefore important to employ strategies that ensure optimum performance of biogas plants in order to win as many adopters as possible and in the process contribute to sustainable environmental management. Use of persons with appropriate technical skills is one such strategy.

Apart from artisans, owners of biogas plants should be given basic training to enable them manage minor repair and maintenance challenges that may lead to a breakdown of bio-digesters (Ghimire, 2009). One of the major challenges faced by adopters was low end-user awareness on how to manage biogas plants such that even when there is a slight fault some of them cannot fix it. This affects functioning of the plant and in some cases can lead to shut down of a number of them thereby denying adopters benefits of their investment. Low end-user awareness and lack of post-installation service had discouraged some people from adopting biogas technology in Kiambu County. Trained technicians should therefore be involved in not just installation of plants but also repair, maintenance and post-installation service because technical support is critical in expanding adoption of biogas technology (Obwogi, 2014; Ngo *et al*., 2017).

2.7.15 Labour Intensive

The perception that production of biogas is a labour-intensive activity that requires additional effort has had a negative impact on the technology (Tucho, *et al*., 2016). The entire process of looking after cattle, gathering and mixing animal waste, among others is considered by some people as too tiring.

However despite challenges, biogas technology is slowly gaining recognition in Kenya. Decreasing vegetation cover, pressure on land and the rising cost of energy are among reasons that have made biogas to be appreciated by eligible households and institutions in high potential areas. For the technology to gain more adoption, stakeholders must initiate strategies that will make it more acceptable to the community.

2.3 Sources of Household Energy in Kiambu County

2.3.1 Wood Fuel

The major source of household energy in Kiambu is wood fuel, particularly in the rural areas where firewood is used on a large scale, while in urban centres charcoal is used majorly by those in the lower economic bracket. Firewood accounts for 47.3 % of household energy in Kiambu (CIDP, 2013 – 2017). It is sourced from individual farmers' lands, local bushes and government forests hence the distance from the source of wood fuel to where it is sold plays a considerable role in determining its retail price. Weather conditions also determine the price of wood fuel: the demand for this resource for warming houses goes up during the cold season and so does the price.

The continued increase in population in Kiambu County exerts additional pressure on the remaining tree cover and this is because firewood was previously easily available and this encouraged people to prefer it as a form of energy. Soil fertility is affected by loss of tree cover, an occurrence that can be avoided through adoption of biogas technology (Mulinda *et al*., 2013). Those in need of wood fuel will continue covering longer distances and spend a lot of time in search of the commodity unless systems are put in place to ensure sustainable forest management and more people are made aware of benefits of biogas compared to wood and fossil fuels. Part of the sensitization in this regard would be to enlighten the community on the potential of biogas as a guarantor of sustainable development.

2.3.2 Kerosene

This is used principally to provide light at night through hurricane lamps and is sourced from local trading centres (Gatama, 2014). Continual use of kerosene poses health risks such as respiratory diseases and eye irritation as well as environmental pollution. One can also be exposed to accidental burns and explosions particularly if the fuel is obtained from unscrupulous traders who adulterate it to maximise on profits.

2.3.3 Electricity

Electricity is supplied from the national grid with 98% of urban centres in the county enjoying connectivity but connection to homes is low (CIDP, 2013 – 2017). Efforts are being made under LMCP and the Rural Electrification Programme (REP) to increase the percentage of residents who have power in their homes (CADP, 2018-2019). At the domestic level electricity is used primarily for lighting and operating electrical appliances unlike in the trade centres where it is used largely for commercial purposes. Although government efforts in supplying electricity to homes, market centres and institutions were commendable, the main setback was security of supply characterised by frequent and at times prolonged black outs as well as low voltage during peak hours.

Electricity supply challenges in Kiambu can be partially addressed through generation of additional power by constructing small hydro stations on some of the big rivers in the county. Thika Falls in Thika sub-county offers a good opportunity for production of hydro electric power that would be of great benefit to the community (MOEP, 2018). The decision on the type of energy to be used at home is determined by factors such as availability, efficiency, cost and reliability.

2.3.4 Liquefied Petroleum Gas

LPG is sourced from local market centres within the county, with most residents using the 6 kg and 13 kg cylinders. Before liberalisation of the oil and gas sector in Kenya in 1994 (Sessional Paper No. 4, 2004; ERC, 2018) it was only the major oil companies like Agip, BP, Caltex, Shell and Total that were involved in LPG trade. Despite its convenience, the cost of re-filling and transport logistics can be a challenge.

2.4 The Role of Biogas in Realization of Sustainable Development Goals

The United Nations (UN) launched the Sustainable Development Goals (SDGs) in 2015 as an avenue for spearheading social-economic development at the global level, but especially for the developing countries. The 8 Millennium Development Goals (MDGs) preceded the SDGs and their objectives ranged from eradicating extreme poverty and hunger to creating a global partnership for development. The major agenda of the MDGs was to meet the needs of the poorest people in the world within a time frame of 15 years (2000-2015). At the end of this period over one billion people were lifted out of extreme poverty but several targets remain unfulfilled (UN, 2015).

The MDGs were succeeded by 17 SDGs in 2015, with each goal having specific targets to be achieved within 15 years. The broad agenda of the SDGs is to end poverty, protect the planet and ensure prosperity for all by the year 2030 and it is instructive to note that this can only be possible if clean and affordable energy such as biogas takes a prominent position in the SDG agenda. Biogas is capable of facilitating achievement of 9 of the 17 SDGs as will be shown in this section (EBA, 2017, WBA, 2017).

2.4.1 Goal Number 1: End poverty in all its forms everywhere

Biogas can be used to generate electricity for industries through which people can be employed. These can be small enterprises or even big industries and apart from employment people can gain skills that will improve their livelihoods. In Limuru sub-county one milk processing company uses biogas in its operations and had engaged several people in the employment chain – cattle handlers, drivers, cashiers and so on. The employees have a source of income while the company saves money that would have been used to pay for expensive and unreliable electricity from the national grid. Using biogas in the transport sector would also create job opportunities for different cadres of people required for its operations (Ammenberg *et al*., 2018).

Adopters can be appreciated through carbon trading which would enable them earn an income for their role in environmental stewardship (IGAD, 2015, Githiru, 2016). Such a measure can encourage others to adopt and thereby help in diffusion of the technology. Using biogas to provide light enables school-going children to spend more hours studying thereby improving literacy levels. In this way they can gain higher levels of education and training that would usher then into the world of work (KEBS, 2013). Other economic activities can also go on beyond sunset.

Because of the close relationship between energy, poverty and human underdevelopment (Bloyd and Bloyd, 2001), access to affordable energy is a *sine qua non* for achieving economic growth and poverty alleviation (Araldsen, 2016). For example investment in biogas would help in lifting about 3.1 million people in Kenya out of poverty as well as improving the country's GDP by the year 2030 (Wagner, 2017). Availability of affordable clean energy can therefore act as a trigger to social-economic improvement that would help in realization of goal number 1.

2.4.2 Goal Number 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture

This can be achieved by utilizing slurry from the bio-digester. Slurry helps to improve soil fertility because it is rich in nutrients and studies have confirmed that it is better than chemical fertilizer (Gitonga, 1997). As organic fertilizer, slurry increases crop production per unit area thereby contributing to sustainable agriculture and food security (EBA, 2017). A food secure nation is free of hunger, malnutrition and other illnesses resulting from food deficiency. The country saves money that would have been spent on food imports and treatment of malnourished citizens, and whatever is saved can be used to promote sustainable agriculture. Food security enables citizens to participate in productive activities while farmers can sell extra harvests to boost their income and simultaneously contribute to ending poverty as envisaged, again, in goal number 1. Investment in biogas technology can also help in improving the dairy industry that would be characterised by increased milk production, food security and employment creation.

2.4.3 Goal Number 3: Ensure healthy lives and promote well-being for all at all ages

Utilization of biogas greatly reduces incidents of indoor air pollution (IAP) that is caused by using wood fuel or animal dung for cooking and heating. It has been estimated that over 4 million people die prematurely every year from illnesses related to IAP (UNDP, 2018; WHO, 2018). The most affected are women and girls as they have to spend many hours preparing meals in smoky kitchens. Biogas contributes to improved household sanitation, reduction in premature mortality rates and savings on medical bills due to decreased cases of smoke-related ailments (Alayi *et al*., 2016).

In the course of producing biogas, different types of biodegradable waste are handled and in the process the stench is minimized while disease-causing pathogens are eliminated (Avery *et al*., 2014). The risk of being infected by different diseases is reduced, enabling people to live healthy and productive lives.

2.4.4 Goal Number 5: Achieve gender equality and empower all women and girls

Partly due to tradition and culture, women and girls bear the brunt of energy challenges in the homestead as they have to ensure that fuel is available for cooking and heating (Osiro, 2015). Adoption of biogas technology would save them the time consuming and laborious burden of fetching firewood from distant places and cooking in smoky kitchens, among other energy-related hardships. It has been estimated that women who use biogas can save up to 50% of their cooking time, which would then be used in other productive activities (Ding *et al.,* 2014). The decreasing forest cover means women and girls have to go far in search of firewood, sometimes even to unsafe places. But through use of biogas, they will save time spent fetching wood fuel and utilize it productively on other activities such as education, training and commerce because biogas contributes to a clean kitchen environment and convenient cooking.

Because of their central position as primary energy managers, stakeholder policies and the gender dimension on energy must factor in concerns of women (Sessional Paper No. 4, 2004; UNDP, 2004; Karki *et al*., 2015; UN, 2016). This would give then a vantage point to fully participate in the spread of the use of sustainable modern energy. Particularly in the rural areas, women are responsible for providing household fuel and giving them access to clean energy will empower them as far as home management is concerned. More capacity building and affirmative action still needs to be done in the gender realm so that women’s involvement in up-scaled adoption of biogas as a clean source of energy can become significant. For the energy situation to be improved in Kiambu County, women must be involved in the planning, implementation and monitoring of biogas projects.

The Wangari Maathai Institute (WMI) for Peace and Environmental Studies at the University of Nairobi has taken the initiative of capacity building and empowerment to train women as masons so that they can install biogas plants in their localities. By partnering with organisations like the Green Belt Movement (GBM) and Partnership on Women's Entrepreneurship in Renewables (wPower), WMI has trained women who live next to Kereita Forest in Lari sub-county on various aspects of Clean Energy Technology (CET) and other environment-friendly approaches because their neighbourhood has been severely affected by encroachment of the forest for wood fuel (GBM, 2014). Empowering women on matters to do with renewable energy would be one avenue of bringing about gender parity particularly for the poor and disadvantaged ones in the rural areas. Gender mainstreaming is therefore a critical factor in sustainable development.

2.4.5 Goal Number 6: Ensure availability and sustainable management of water and sanitation for all

Bio-solids are recycled through anaerobic digestion then used as bio-fertilizer to boost soil fertility and increase farm yields. In this way, contamination of soil and water by unprocessed organic material is minimized if not avoided. Biogas technology therefore reduces the risk of surface and ground water contamination through conversion of waste into energy (Ali *et al*., 2013).

2.4.6 Goal Number 7: Ensure access to affordable, reliable, sustainable and modern energy for all

This goal makes specific reference to clean energy as the major factor that can trigger social-economic development across the globe given the significant contribution of energy in human existence. Energy occupies the central part of the sustainable development agenda to 2030 yet inability to access affordable, reliable and efficient energy has continued to trap millions of people across the globe in a vicious circle of excruciating poverty (Karki *et al*., 2015). At present approximately 1.1 billion people have no access to electricity and another 2.8 billion have no access to clean cooking facilities (IEA, 2018). Such people are forced to use non-clean energy sources like wood fuel and animal dung that expose them to chest complications, eye irritation, respiratory ailments and other impacts of IAP. They cannot effectively participate in the social-economic development of their countries and their varied potential will remain unrealized as long as the energy gap exists. As indicated, the most affected are women and girls but investment in biogas technology would go a long way in providing energy that will save them from the back-breaking and dangerous tasks of fetching firewood from far off places and performing kitchen duties in unhealthy surroundings.

One advantage of biogas is that it is generated from locally available feedstock and as clean energy is being produced the environment is simultaneously kept clean. Availing clean energy such as biogas opens up many opportunities that those outside the national grid could not access for a very long time such as education, medical care, commerce and a general improvement in standards of living (CGIAR, 2017). The abundance of substrate makes it easier for biogas to be made available to as many people as possible. Apart from initial installation charges, biogas technology is almost maintenance-free and this increases its potential of accessibility by a bigger percentage of the global community (Muriuki, 2014). Conventional forms of energy, particularly fossil-based fuels had proved untenable and this calls for special attention to be given to renewable energy sources like biogas because of their sustainability.

Production of biogas therefore meets a need (access to energy) and provides a solution to various environmental, social and economic challenges. Because of the vital role of energy in human development, attainment of SDG number 7 can play a major role in realization of the other SDGs (UN, 2015).

2.4.7 Goal Number 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

This can be achieved through generation of biogas from effluent emitted by factories and using the same to run those facilities, thereby contributing to the self-sufficiency and sustainability of industries (WBA, 2017). Any excess energy generated can be used to operate Small and Medium Enterprises (SMEs) in the neighbourhood or even deployed to the national grid for distribution to other parts of the country.

2.4.8 Goal Number 11: Make cities and human settlements inclusive, safe, resilient and sustainable

Proper collection and management of organic waste for production of biogas plays a crucial role in preventing the spread of diseases, especially in urban centres. Converting effluent from factories, slaughterhouses, sewage systems and other institutions into biogas is a strategic way of making human settlements safe for habitation (Trivedi *et al*., 2015; Bong *et al*., 2017).

Poor air quality in many urban centres across the globe has subjected them to periodic incidents of choking fog and smog that is harmful to human health. For the last few years, a number of Asian cities have been repeatedly clouded in smog resulting from the use of coal in production of electricity and heating. The most affected city has been the Chinese capital, Beijing where thick toxic fog has become a common phenomenon that forces the authorities to issue “red alerts” warning people to take precautionary measures including wearing respiratory masks(Chen *et al*., 2015). Poor visibility, disruption of traffic, closure of educational institutions and other inconveniences are now familiar happenings in Beijing and sometimes the poisonous fog may have a concentration of harmful particles that is way above what is recommended by the World Health Organisation (WHO, 2017).

Fortunately urban air quality can be improved partly by using biogas for cooking and heating instead of wood fuel, coal or oil (Alayi *et al.*, 2016). Similarly biogas can be upgraded into Compressed Natural Gas (CNG) or bio-methane to be used by vehicles and industries instead of hydrocarbons (Kennes and Veiga, 2013; Bhatia, 2014; Feroldi *et al.*, 2016; Singhal *et al*., 2017).

2.4.9 Goal Number 13: Take urgent action to combat climate change and its impacts

Greenhouse gas emissions that are a major contributor to climate change and global warming can be mitigated through use of biogas in homes, the transport sector, industries and other institutions instead of wood fuel, petroleum, coal, heavy fuel oil or industrial diesel oil (Uhiene, 2017; WBA, 2018). Similarly using slurry instead of chemical fertilizer reduces carbon emissions that would have been released into the atmosphere during production and transportation.

Methane (CH_4) is one of the most potent greenhouse gases with a global warming potential that is 21 times more than carbon dioxide (CO_2) but through anaerobic decomposition of biodegradable material it is transformed into clean energy that does not contribute to climate change (Islam and Hossein, 2014). Using biogas instead of wood fuel reduces carbon emissions, saves trees, protects the ecosystem and contributes to a clean and healthy environment.

2.4.10 Goal Number 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Through anaerobic digestion, nutrients and organic matter in the feedstock are recycled and returned to the soil as digested substrate. In this way soil fertility is enhanced resulting into higher yields per unit area thereby removing the need to expand agricultural land in order to increase harvests (Heegde and Sonder, 2007; CGIAR, 2017). Using biogas instead of wood fuel contributes to sustainable management of forest resources that helps in mitigation against deforestation and destruction of biodiversity. Protection of biodiversity and the ecosystem plays a significant role in environmental sustainability which in itself is a principal ingredient of sustainable development (Yadav, 2014). Therefore reduction of environmental degradation through use of biogas helps to sustain and even enhance the capability of forests to act as carbon sinks.

Biogas therefore has the potential of facilitating realization of the SDGs which would bring about environmental, social and economic benefits to many people across the globe (Alayi *et al*., 2016; Surie, 2017; WBA, 2017). It is for this reason that adoption and use of biogas as a clean form of energy ought to be given support by all stakeholders because of the positive changes it can bring to mankind.

2.5 Potential of Kiambu County for Biogas Production

There is enormous potential for biogas development in Kiambu that needs to be optimally exploited so as to contribute to the community's environmental, social and economic well being. Maximum utilisation of locally available resources, appropriate policy frameworks, involvement of all key stakeholders and application of other relevant support systems are some of the strategies that can facilitate up-scaling of adoption and utilization of biogas technology in the community (Mengistu *et al*., 2016). For adoption and use of biogas to take root, policy frameworks that buttress its sustainable development are indispensable (Andreas and Schlegel, 2006). This is evident in countries where renewable energy is a major contributor to their social-economic progress and environmental sustainability (Jaramillo-Nieves and Del Rio, 2010; EU, 2016; Sari and Akkaya, 2016).

Enhanced adoption of biogas technology in Kiambu would be in line with Kenya's national policies that seek to not only increase access to modern forms of energy but also to promote use of clean energy technologies (Sessional Paper Number 4 on Energy, 2004; SE4All, 2016). In this way the local community would be playing their role in realization of the Sustainable Development Goals, and more so SDG number 7 on availing clean energy to all. Increased uptake of biogas would also contribute to realization of objectives of Kenya's Vision 2030 blue print.With the potential of generating up to 1,000 MW of electricity (ERC, 2018), biogas is a green energy technology that has the capacity to offset various negative impacts related to use of wood and fossil fuels in Kiambu and Kenya as a whole. If fully exploited biogas has the potential of contributing to the sustainable development of Kiambu County and Kenya as a whole.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Design and Sampling

3.1.1 Study Area

The research was carried out in Kiambu County (Figure 6), which previously formed part of Central Province until the promulgation of the 2010 Constitution that divided Kenya into 47 counties. It lies between latitude 1.1462° S and longitude 36.9665° E. Kiambu shares borders with five other counties, namely Nakuru and Kajiado to the West, Murang'a and Nyandarua to the North and Nairobi to the South.

Figure 6: Location of Kiambu County in Kenya

Source: County Government of Kiambu

The county was selected for the study because it is a rich agricultural area with a thriving livestock sub-sector (CGK, 2017). In Kenya most biogas plants use cattle dung as feedstock and since it is plenty in Kiambu, the study sought to investigate ways and means of exploiting this resource in enhanced adoption of clean, reliable, affordable and sustainable energy. Apart from cattle dung there are other resources that can be used to generate biogas such as agricultural residues and municipal waste but they are hardly utilized for the purpose.

The following section will provide basic information about the study area which should help in having a fairly good understanding of Kiambu County. This would eventually enable one have a better understanding of the research topic because the issues discussed have a bearing on adoption of biogas technology.

3.1.2 Administrative and Political units

Currently, the county is divided into twelve (12) sub-counties (Figure 7) namely Limuru, Kikuyu, Kabete, Lari, Gatundu South, Gatundu North, Githunguri, Kiambu, Kiambaa, Ruiru, Juja and Thika Town. These are further divided into sixty (60) wards.

Figure 7: Map of Kiambu County showing the 12 sub-counties

Source: County Government of Kiambu

3.1.3 Climate and Weather

The county enjoys a warm climate with average temperatures ranging between 12°c and 18.7°c. Aggregate annual rainfall is 1,000 mm and the cool climate makes it suitable for farming through which resources for generation of biogas such as animal waste and agricultural residues are produced. The coldest months of the year are June-July that are characterised by drizzles, thick fog and at times frost, while January-March and September-October are the hottest months (Kenya Information Guide, 2015). Demand for energy goes up during the cold months, particularly charcoal and firewood for warming houses which increases destruction of forest resources and pollutes the atmosphere. These negative impacts of using conventional forms of energy can be mitigated by using clean energy like biogas. Kiambu County has four broad topographical zones, namely: Upper Highland, Lower Highland, Upper Midland and Lower Midland Zone.

3.1.4 Ecological Conditions

The county gets water from rain, rivers, swamps and underground sources. Water is important in generation of biogas as cattle need sufficient amounts of this resource as part of their diet while mixing of dung also requires water. The resource is invaluable in keeping the animals and their sheds clean. So far the County government has provided 35% of the population with portable water (CIDP, 2013 – 2017).

3.1.5 Demographic Features

The population of Kiambu County as per the last census is 1,623,282 (KNBS, 2010) and was projected to reach 2,032,464 by the end of 2017 (CIDP, 2013 – 2017). Although majority of the inhabitants are of the Kikuyu tribe, it is a cosmopolitan area with people from all ethnic groups in Kenya. There is also a sizeable population of Asians, Europeans and other racial groups/nationalities.

3.1.6 Social Economic Regime: Trade and Agriculture

Several commercial activities take place in Kiambu County including retail business, transport, real estate, hospitality, provision of education, among others and they vary in their size and complexity. Agricultural activities include cultivation of coffee, tea, maize, beans, horticulture and dairy farming on small and large scale basis (CGK, Department of Agriculture, Livestock and Fisheries, 2018). Since it borders Nairobi, Kiambu has the comparative advantage that comes with being next to a capital city and all that this offers in terms of economic benefits. Nairobi provides a ready market for a variety of goods and services from Kiambu County.

3.1.7 Social Amenities

The county has a fairly high level of social amenities like schools and medical centres all of which have attracted people from different parts of the country. In terms of educational institutions, some of the oldest and well known schools in Kenya are found in Kiambu County, eg Alliance Boys' High School. The most renowned institution of higher learning in Kiambu is the Jomo Kenyatta University of Agriculture and Technology (JKUAT). Availability of educational institutions increases literacy levels and can help in a community's understanding of green energy issues such as benefits of adopting biogas technology. Indeed JKUAT offers training in various aspects of biogas technology (www.jkuat.ac.ke).

3.1.8 Transport Infrastructure

The county is served with tarmac, all-weather and earth roads whose total length is 3,944.1 kilometres (CIDP, 2013-2017). The roads link Kiambu with other parts of the country, the most outstanding one being the Chinese built Thika Superhighway that joins Kiambu with Nairobi and Murang'a counties. Access roads to the interior are being rehabilitated by the County government to open them up for development. Railway services are also evident and part of the Kenya-Uganda Railway traverses the county covering a distance of 131 kilometres. A reliable transport system plays a significant role in development of biogas technology, particularly with regard to ferrying necessary materials such as the bio-digester, sand, cement, animal feeds, feedstock and slurry.

3.2 Research Design

3.2.1 Pilot Study

A questionnaire was prepared and used for the pilot study that took place from September-December 2016. The pilot study was carried out to validate the effectiveness of the research instrument and ascertain the authenticity regarding biogas potential in Kiambu County. A pilot study is important as it increases the likelihood of success of the main study (Teijlingen and

Hundley, 2002). By using local contacts, information about those who had adopted biogas technology in seven sub-counties was obtained during the pilot study. The sub counties were:

i. Githunguri,
ii. Lari
iii. Limuru
iv. Ruiru
v. Thika
vi. Kabete
vii. Kikuyu

The 7 were chosen because of their perceived potential in production and use of biogas that was cited from published secondary data. Upon confirmation of the potential of biogas production in Kiambu County, it was found that out of the seven sub-counties, four (Githunguri, Lari, Limuru and Ruiru) offered the best area of study due to the presence of critical resources that are significant in production of biogas namely high numbers of livestock, fodder, water, municipal waste, effluent from factories and slaughterhouses, among others. Residents of the four administrative units also had a reasonable level of understanding of biogas as a form of clean energy. Because of their evident potential in enhanced production and utilization of biogas technology, the four sub-counties became the focus of the study that took place from January to December 2017.

A permit was obtained from the government of Kenya through the National Commission for Science, Technology and Innovation (NACOSTI) as well as from the Wangari Maathai Institute

(WMI) for Peace and Environmental Studies. Three Research Assistants were recruited to help in data collection and they were briefed on how to conduct the exercise. The work took one year to accomplish and three months writing the thesis.

Data Collection

Instruments for data collection were questionnaires, research diaries, a camera, data record sheets, checklists and observational data sets.

3.2.2 Sources of Data

Primary and secondary data was used for the research; the former was obtained from the field and the latter through desktop research.

3.2.3 Sampling

It was practically impossible to incorporate all households in the study and so a sampling frame was used to select the number of households for the study per sub-county. The household was identified as the primary sampling unit for evaluating factors affecting uptake and adoption of biogas and data was collected from 416 households of which 208 had adopted biogas technology while another 208 had not adopted it. The target population for the four sub-counties was 2,000 households and the Sample Size Calculator was used to determine the sample population. Using a confidence level of 95% and a confidence interval of 5%, the sample size (n) came to 322 households. However, out of the 500 questionnaires that were distributed to respondents, a total of 416 were returned giving a response rate of 83.2% which was 20.8% of the target population and is regarded adequate for analysis of descriptive study (Mugenda and Mugenda, 2003).By having respondents who were more than the minimum sample size made it possible to get views of a wider number of people from varying social-economic backgrounds. Systematic and random sampling methods were used in selecting the households. For random sampling the transect line of survey was used to pick every fifth household in four wards of the four sub counties. One of the advantages of simple random sampling is that each member has an equal chance of being sampled and as such it removes bias from the selection process (Gravetter and Forzano, 2011).

Sampling was carried out in four administrative wards in each of the sub counties to ensure fair representation of respondents. From each of the four wards in the four sub counties, 13 adopter and 13 non adopter households were sampled. Data collection was done through interviews, questionnaires, observation, research diaries, data record sheets, a camera, checklists, maps, diagrams, focused group discussions, (FGD), key informant interviews (KII) and expert opinion. The data collected included names of respondents, gender, age group, level of education, main source of energy, income levels, whether they had adopted or not adopted biogas technology and reasons for their choice of energy (Appendix 9.1).

The purposive sampling procedure was used to get data from key informants such as government officials because they had specific information that the study was seeking. In this respect, purposive sampling offered the best approach particularly in terms of saving time and other resources.

3.2.4 Focus Group Discussions

These were women and youth groups and through them information on biogas in Kiambu was obtained. Through free discussion and exchange of views, factors that had contributed to the low adoption of biogas technology in Kiambu came up. What was got through questionnaires was corroborated with what was raised during focus group discussions. Focus groups enable people who, for whatever reason, may not wish to be interviewed on their own to gain courage and have the confidence of giving their views (Kitzinge, 1995).This method also allows the researcher to get more information about a subject in one sitting while at the same time giving participants an opportunity to learn from one another.

3.2.5 Data Processing and Analysis

Data was analysed using quantitative and qualitative techniques: quantitative data was analysed using descriptive statistics such as frequencies, percentages and means and the significance tested using Chi-square test ($P \leq 0.05$).Qualitative data was reported in narrative form and similarly tested using Chi-square test ($P \leq 0.05$).

CHAPTER FOUR

4.0 Demographic Factors that Affect Adoption of Biogas Technology in Kiambu County (International Journal of Innovative Research and Knowledge, 3 (1): 48-57).

4.1 Abstract

Biogas is produced through anaerobic digestion of organic feedstock materials. Biogas is an important source of green energy and the growth of its production in Kenya is mainly supported by co-digestion of manure. Economic and institutional factors have been identified to affect the success of the Kenyan biogas sector. This paper reports the demographic factors affecting adoption of biogas technology in Kiambu County. Data was collected by surveying 416 (n=208 households producing biogas and n=208 households not producing biogas). Households were randomly selected using the transect line survey of every fifth household in four sub-counties in Kiambu. Equal distribution of sampled households was ensured for each ward sampled (n=13 for households producing biogas and n=13 for households not producing biogas). Biogas technology adoption rate in Kiambu was low (about 25%) and this was even lower in female-headed households (33%). Other demographic factors that significantly influenced biogas production in Kiambu included age of the household head, the main farming activity practiced, land ownership tenure, livestock keeping activity, and household income level (n=416, $P \leq 0.05$).However the respondents' education level did not significantly influence the adoption rate. It is recommended that policy on biogas adoption is not only based on the need to decrease environmental pollution

but also the need to address the challenges arising from demographic disparities in the communities.

Keywords: Biogas, Adoption, Demographic, Determinants, Kiambu

4.2 Introduction

Biogas technology is a solution to many adverse health and environmental impacts (Brown, 2006; Yadav, 2014; Inda and Moronge, 2015). Biogas is a mixture of gases produced through anaerobic digestion of biodegradable material like manure and other green waste from plant material and energy crops, particularly corn (Karanja and Kiruiro, 2013; CEF, 2016). These feedstock raw materials are decomposed through anaerobic digestion by the micro-organism to transform into biogas. Biogas is principally composed of methane (CH_4) and carbon dioxide (CO_2) and it is a combustible high grade fuel that burns with a hot blue flame. It is considered clean energy for heating, cooking, lighting and powering engines. Biogas is considered to be a clean, renewable source of energy because during heating it does not produce carbon dioxide (Kangmin and Ho, 2006; Jørgensen, 2009; CEF, 2016; Renewables, 2016). In addition biogas offers benefits such as saving wood fuel and protecting forests as well as reducing expenditure on fuels. It further reduces household labour on time spent on cooking and housekeeping and improves hygienic conditions (Gregory, 2006).

If fully exploited, biogas has the potential of providing up to 6% of global primary energy supply equivalent to a quarter of the current consumption of natural gas (WBA, 2013; GBA, 2016). This would address challenges posed by use of fossil-based forms of energy, particularly leading to a cleaner environment (IFG, 2004). Today more and more countries are making efforts to adopt the use of renewable energy because it is clean and sustainable. Indeed it has been noted that renewable energy is by far, the fastest growing source of fuel in the world (BP Energy Outlook, 2018). Kenya is advocating, in her Vision 2030 agenda, the use of clean energy such as biogas for environmental, social and economic benefits. Kiambu County hosts many farms that can produce and benefit from biogas production. However, even with all the effort by the various agencies to promote biogas, 80 % of people in Sub-Sahara Africa rely on traditional use of biomass for their cooking (Rogers, 1995; Karekezi and Kithyoma, 2003), with over 90% of rural households in Kenya using wood fuel for cooking (Muriuki, 2014; Njenga, 2013).

This paper documents the demographic factors affecting the adoption and use of biogas in Kiambu, which is a high potential area for generation of biogas (Shell Foundation, 2007). Thus, with the prerequisite support mechanisms the current production in Kiambu could be increased for use within and outside the County. This would lead to benefits such as low cost of energy, reduction in environmental degradation and promotion of sustainable development.

4.3 Materials and Methods

The research was carried out in Kiambu County in Central Kenya using the conceptual framework shown in Figure 8. The County is divided into 12 sub-counties and four of them were purposely selected based on geographical location for uniform representation as follows; Githunguri, Lari, Limuru and Ruiru sub-counties. In addition the selected sub-counties met the criterion for high potential for biogas production based on existing secondary data. The data was collected by administering questionnaires to 208 heads of households producing biogas and also to another 208 from non biogas producing households, who served as the control group. The data was also corroborated through key informant interviews conducted using institutional authorities. Questionnaires, research diaries, data record sheets, checklists, observational data sets, photographs, focus group discussion recordings and key informant interview reports were used for this research.

The household was used as the primary sampling unit to evaluate the demographic factors affecting biogas production and use. The sampled households were 416 (n=208 households producing biogas and n=208 households not producing biogas). All households were randomly selected using the transect line survey of every fifth household for each of the four administrative wards in each sub-county. Equal distribution of sampled households was ensured for each ward sampled (n=13 for households producing biogas and n=13 for households not producing biogas in each ward). This ensured each household had equal chance of being sampled to avoid bias in the selection process as previously described by others (Gravetter and Forzano, 2011).Both quantitative and qualitative data were collected. Quantitative data was analysed using descriptive statistics while qualitative data was tested using Chi-square test ($P \leq 0.05$)

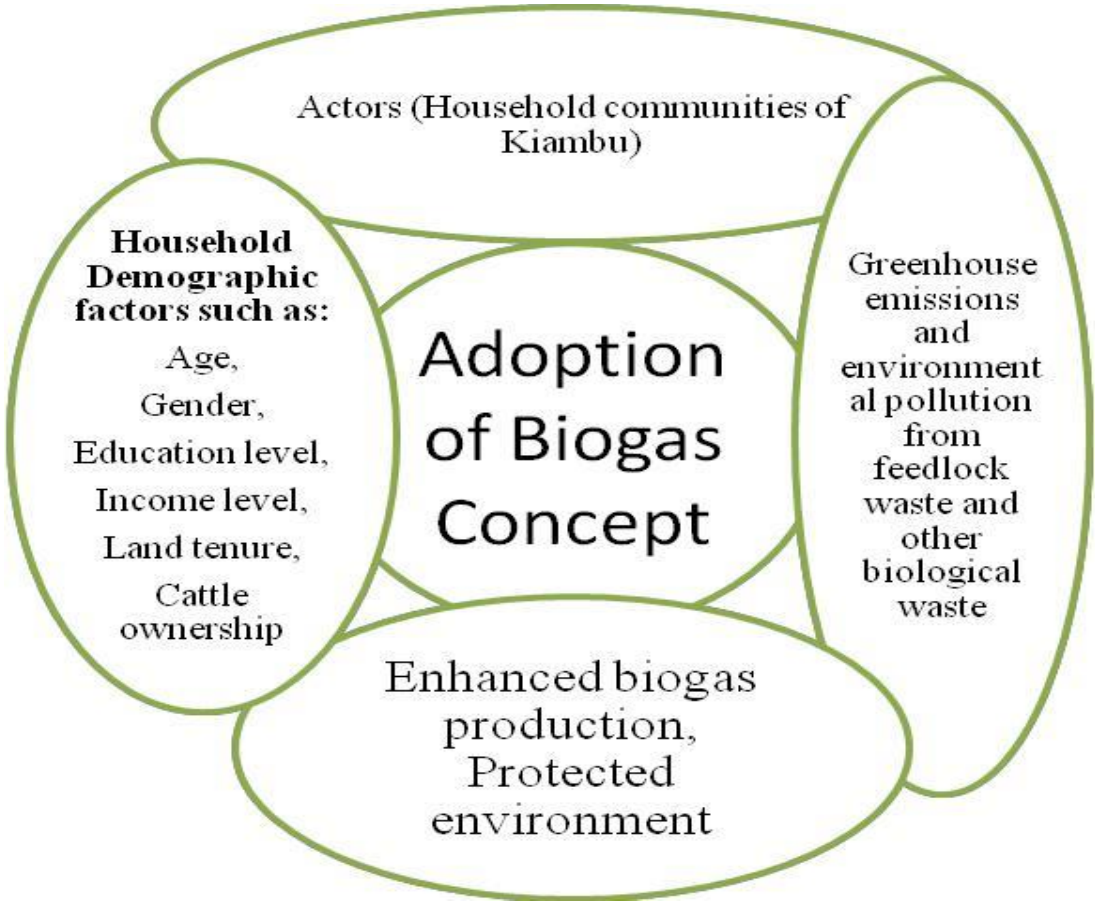

Figure 8: The conceptual framework for adoption of biogas for enhanced environmental management.

4.4 Results and Discussion

4.4.1 Gender effects on biogas technology adoption

In general there was significantly low adoption rate for biogas technology within both male and female-headed households (39% against a non-adoption rate of 61% in male-headed households and 33% against 67% for female-headed households). Also gender of the household head significantly affected adoption of biogas technology in Kiambu (Table 1). Significantly higher adoption rate for biogas technology was noted in male- headed households (39%, n=300, P≤0.05 when compared to female-headed households (33%, n=116, P≤0.05).

Table 1: Gender effects on adoption rate of biogas technology within Kiambu households (n=416)

Parameter		Adopted %	Not Adopted %
Gender	Male (n=300)	38.9 ± 2.1^{a1}	61.1 ± 1.7^{b1}
	Female (n=116)	33.1 ± 1.6^{a2}	66.9 ± 1.8^{b2}

$^{a-d}$ Different letters and numbers in the same row and column differ statistically by Chi-square, P<0.01; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice

In Kiambu, just like in most African communities, men own most household assets in male-headed households. Thus, it was expected they would be the main gender deciding whether to adopt or not adopt biogas technology. A study carried out in Nepal made a similar conclusion (Karki *et al.*, 2015). This could point towards a need by national and county governments to prioritize policies on energy that take into account the concerns of women because of their critical role in the paradigm shift towards use of clean energy based on the fact that they are the gender involved in firewood searching and cooking for families (Obisesan, 2014). Similar results were reported by Wawa (2012), who found out that gender of the household head influenced the decision to adopt biogas technology. Male-headed households were more likely to adopt biogas than female-headed households. The patriarchy system where men own resources and they are the decision makers (Njenga, 2013) gives them an advantage to make the decision for or against adoption of biogas.

4.4.2 Effect of age of respondents on biogas adoption

Apart from between age group 20-40 years, there were significant differences ($P\leq0.05$) between the age groups on adoption and/ or non adoption practices for biogas in Kiambu (Table 2).

Table 2: Effect of age of respondents on adoption of biogas technology (n=416)

Parameter		Adopted (n=208)	Not Adopted (n=208)
		Percentage %	Percentage %
Age	20 – 30 Years	18.5 ± 1.3^{a1}	81.5 ± 1.6^{b1}
	30 – 40 Years	19.7 ± 0.8^{a1}	80.3 ± 0.9^{b1}
	40 – 50 Years	29.1 ± 1.1^{a2}	70.9 ± 1.4^{b}
	50 – 60 Years	38.9 ± 2.3^{a2}	61.1 ± 1.5^{b2}
	Over 60 Years	51.0 ± 0.7^{a2}	49.0 ± 0.4^{b2}

$^{a-d}$ Different letters and numbers in the same row and column differ statistically by Chi-square, $P<0.01$; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice

The data confirms that young people (age 20-40) had low adoption rate for biogas technology as also reported previously by others (Wawa, 2012; Kinya, 2014). This could be explained by the fact that this age group prefers sources of energy like hydro electric power and solar which to them are not labour-intensive when compared to biogas production and the fact that the older generation controls the household land and capital for such investments

4.4.3 Effect of education level of respondents on adoption of biogas

Education level had no significant effect on adoption and/ or non adoption practices for biogas in Kiambu (Table 3, $P \leq 0.05$).

Table 3: Effect of level of education of respondents on adoption of biogas

Parameter		Adopted (n=208)	Not Adopted (n=208)
		Percentage	Percentage
Highest level of education	No Education	38.1 ± 0.2^{a1}	61.9 ± 0.3^{b1}
	Primary Education	$25.9 \pm .07^{a2}$	74.1 ± 0.9^{b2}
	Secondary Education	36.5 ± 0.6^{a1}	63.5 ± 0.6^{b1}
	Tertiary Education	36.9 ± 0.9^{a1}	63.1 ± 0.8^{b1}
	Postgraduate Education	33.3 ± 0.1^{a1}	66.7 ± 0.1^{b1}

[a-d] Different letters and numbers in the same row and column differ statistically by Chi-square, P<0.01; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice

This data is contrary to our expected outcome that level of literacy would have enabled household heads to make decisions for adoption of clean energy such as biogas. A literate population is expected to be more trained and sensitized on environmental issues (Wawa, 2012; Mengistu *et al*., 2016). May be this could be attributed to the fact that it is not only the level of education that informs decision on adoption but rather other confounding factors like social, economic and personal decisions (Riddell and Song, 2012). This finding agrees with that of Walekhwa *et al*., (2010) who revealed that the level of education was negatively correlated to adoption of biogas technology because people viewed it as the technology for the less educated.

4.4.4 Effect of farming activity on adoption of biogas technology

There was significant effect of the main farming activity on the adoption rate of biogas in Kiambu (Table 4).There is a direct correlation between farming and adoption of biogas technology.

Table 4: Effect of occupation of respondents on adoption of biogas technology

Parameter		Adopted (n=208)	Not Adopted (n=208)
		Percentage	Percentage
Occupation	Farming	42.7 ± 1.3^{a1}	57.3 ± 1.1^{b1}
	Business	24.8 ± 1.9^{a2}	75.2 ± 1.6^{b2}
	Formal employment	31.4 ± 0.8^{a2}	68.6 ± 1.2^{b2}

$^{a-d}$ Different letters and numbers in the same row and column differ statistically by Chi-square, $P<0.01$; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice

The data agrees with the fact that biogas is expected to mostly come from animal manure (Make It Be, 2012). Thus the amount of bovine, swine and poultry manure available in farms could easily be converted into biogas as long as there is capital for investing in the technology (Reale *et al.,* 2009). This supports the fact that households engaging in agri-business and formal office employment could be engaged in biogas. Thus, the data also support the fact that beyond traditional adoption framework based on farming enterprise, income from other sources becomes a key variable for adoption of this technology by providing the capital needed for setting up biogas facilities (Selden and Song, 1994).

4.4.5 Household income effect on adoption of biogas technology

There was a significant relationship between the respondents' income and adoption of biogas technology (Table 5). However differences were noted that existed between various categories of income levels and the role this played in an individual's decision to adopt biogas technology.

Table 5: Effect of household income on adoption of biogas technology

Parameter		Adopted (n= 208)	Not Adopted (n=208)
		Percentage	Percentage
Average monthly income (Ksh in thousands)	Below 10	12.3 ± 1.7^{a1}	87.7 ± 2.0^{b1}
	10-20	41.7 ± 2.0^{a2}	58.3 ± 1.6^{b2}
	20-30	49.3 ± 0.8^{a2}	50.7 ± 0.8^{b2}
	30-40	$69.0\pm0.4a^{2}$	31.0 ± 0.2^{b2}
	40-50	24.0 ± 0.1^{a2}	$76.0\pm0.b^{b2}$
	Over 50	40.9 ± 0.3^{b2}	59.1 ± 0.1^{b2}

[a-d] Different letters and numbers in the same row and column differ statistically by Chi-square, P<0.01; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice

This data seems to support the notion that energy consumption mainly focuses on the relationship between energy and income (Kalyoncu *et al.*, 2013). Also, the data agrees with recently reviewed energy-growth nexus, which identified prevailing viewpoints on adoption and consumption of energy. These views state that energy is an input of production, and thus correlates energy consumption to economic growth (Stern and Cleveland, 2004). When consumption of commercial energy is high it is usually a reflection of a high rate of economic activities that normally leads to higher levels of GDP. High consumption of commercial energy is thus a major pointer of economic growth and development (MOE, 2004). Therefore it is also agreeable that economic growth influences energy consumption (Toman and Jemelkova, 2003; Aziz, 2011) and that economic development affects energy consumption, and by extension the type of energy adopted (Aziz, 2011). This also agrees with Sufdar *et al.*, (2013) who indicated that households with high income are more likely to adopt biogas technology as compared to those with low income.

4.4.6 Effect of land ownership on adoption of biogas technology

Land ownership significantly influenced adoption of biogas technology (Table 6).

Table 6: Effect of land ownership on adoption of biogas technology (n=416)

Parameter		Adopted %	Not Adopted %
Ownership	Owned (n=208)	36.8 ± 2.3^{a1}	63.2 ± 1.8^{b1}
	Did not own (n=208)	0 ± 0^{a2}	100 ± 0.1^{b2}

$^{a\text{-}d}$ Different letters and numbers in the same row and column differ statistically by Chi-square, P<0.01; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice

This data supports the view that individuals have their own visions about which renewable energy sources are acceptable but a vision of production of biogas in non-owned land would entail responsibility of many actors posing a challenge towards the desire to adopt the technology (Natuur and Milieu, 2011). Access to farms has certain structural advantages regarding bio-energy production, such as land ownership, appropriate machinery and storage facilities.

4.4.7 Effect of cattle ownership on adoption of biogas technology

Cattle ownership significantly influenced adoption of biogas technology in Kiambu County ($P \leq 0.05$). However there were a few instances of adopters who did not own cattle but bought manure for biogas production as shown in Table 7.

Table 7: Effect of livestock ownership on adoption of biogas technology (n=416)

Parameter		Adopted %	Not Adopted %
Ownership	Owned (n=208)	50.5 ± 1.3^{a1}	49.5 ± 2.3^{b1}
	Did not own (n=208)	2.3 ± 0.2^{a2}	97.7 ± 1.8^{b2}

$^{a-d}$ Different letters and numbers in the same row and column differ statistically by Chi-square, P<0.01; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice

This data supports the fact that households owning cattle had certain structural advantages regarding bio-energy production from anaerobic digestion of the manure for biogas production (Iqbal *et al.*, 2013). This was expected because most of the adopters in Kiambu kept cattle on zero-grazing basis making it easier for them to collect feedstock for the bio-digesters. Kiambu practices dairying as a means for household income generation (KNBS, 2010). The results are supported by Kabir *et al.*, (2013) who suggested that cattle ownership is an important step in owning biogas since it provides the substrate required for anaerobic digestion.

4.4.8 Conclusion and Recommendations

The data points towards demographic factor-dependent adoption of biogas technology in Kiambu. This conclusion ties well with the Resource Dependence Theory (RDT) as explained by Nienhüser (2008). The theory states that the success of a venture, like biogas production in our case, depends on the level of dependence on critical resources, in this case as influenced by the above listed demographic factors. Thus, based on the environmental Kuznets curve (EKC) hypothesis, in which the relationship between income and environmental deterioration exists, it is recommended that policy on biogas adoption is not only based on the need to decrease environmental pollution but also the need to address the challenges associated with demographic factors in the communities.

CHAPTER FIVE

5.0 Governance Aspects on Adoption of Biogas Technology in Kiambu County

(International Journal of Innovative Research and Knowledge, 3 (3): 81-86).

5.1 Abstract

Kiambu is one of the metropolitan and fast-growing counties in Kenya where adoption of clean energy would enhance environmental sustainability. However, governance and utilization of energy like biogas is still hampered by barriers of knowledge, attitudes and practices (KAP), among others. The paper examines the relationship between KAP and governance in adoption of biogas technology in Kiambu. Data was collected from 416 households (n=208 households producing biogas and n=208 households not producing biogas) in four sub-counties of Kiambu. Transect line survey of households was done by selecting randomly every fifth household in the study area. There was equal distribution of sampled households for each administrative ward in the sub-counties (n=5 for households producing biogas and n=5 for households not producing biogas). Respondents' knowledge, attitudes and practices on adoption of biogas and its governance indicate that 87.64% of the respondents knew about biogas and its usefulness. Only minority (21%) were aware of the regulatory legislation and majority (85%) did not comply with the regulations. Biogas adoption in Kiambu was low (25%) and that majority of those adopting the biogas technology (98%) are not organized into associations. There was also moderate (50%) institutional support for biogas adoption. Results in Table 10 show that willingness to adopt biogas technology is high in Kiambu (90%), and the felt value addition in being members of biogas user associations is also high (95%). However, the regulation process is weak (21%). It is concluded that there is weak regulation and low adoption of biogas technology in Kiambu. However, potential exists for enhanced adoption of biogas especially through increased institutional and legislation support. There is also need for awareness creation on governance instruments and need to address the capacity gaps existing.

Key words: Biogas adoption, governance, knowledge, attitudes and practices, Kiambu County

5.2 Introduction

Environmental governance is the decision-making process in management of the environment and involves a wide spectrum of stakeholders at the local, national and global levels such as governments, non-governmental organization (NGOs), international organizations and civil society (Muigua and Musyimi 2008; NEMA, 2009; IUCN, 2014; Plummer *et al*., 2017). A conceptual framework was designed to explain the inter-relationship between various actors in environmental governance and the outcome of their interactions (Figure 9). Environmental governance brings excellence in management of the environment by establishing a culture of sustainability that is supported by well thought-out and functional operating systems (Wakiaga, 2018). This is founded on formulation of legal and policy instruments that support decisions with sound outcomes (Olowu, 2007).

Under environmental governance, natural resources such as biogas are considered as **"**global public goods**"** meant for the well-being of mankind (Thalwitz, 2000; Launay and Mouriès, 2003; Kok *et al*., 2011). Thus, biogas needs to be protected at all costs for the benefit of current and future generations. Environmental governance advocates for sustainable utilization of such resources (Kotzé, 2006).The paper focuses on governance of the adoption of biogas in Kiambu County in Kenya in reference to specific regulatory frameworks (Fig. 9). Considerations are based on various actors responsible for its regulation as a green energy resource in Kenya. There is a deliberate effort made to understand how governance has influenced the seemingly slow uptake of adoption despite numerous campaigns for its acceptance in Kiambu (Githiomi *et al*., 2012; CIDP, 2013-2017).

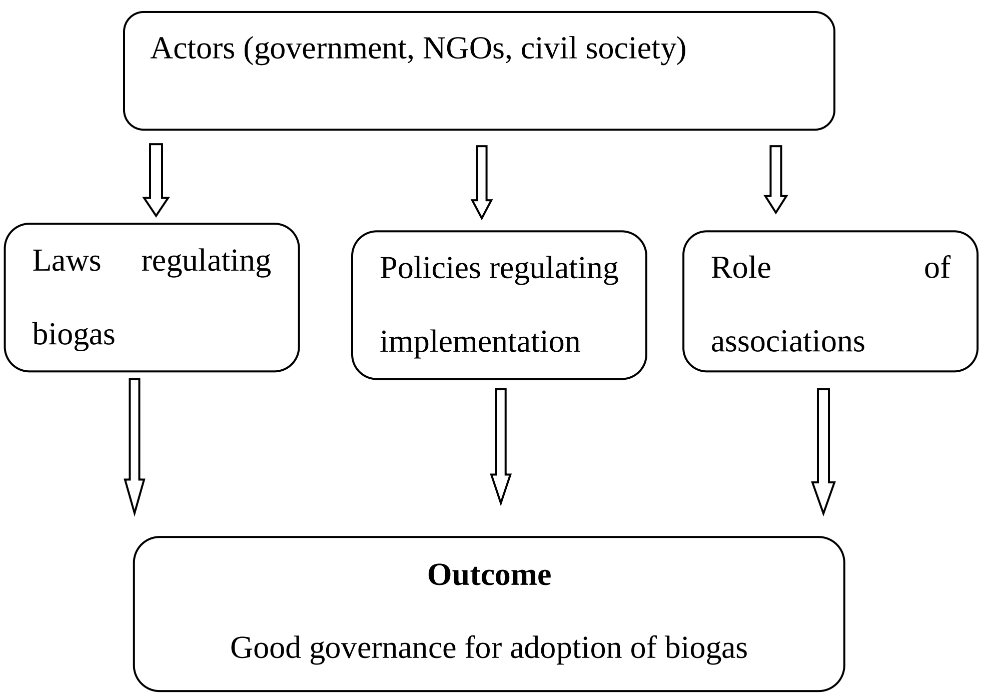

Figure 9: Conceptual framework

5.3 Materials and Methods

The study aimed to understand the governance instruments affecting the adoption of biogas in Kiambu (Fig. 9). The study was conducted in four out of twelve sub counties of Kiambu County, namely Githunguri, Lari, Limuru and Ruiru using a standard questionnaire as previously described (Kavisi *et al*., 2018). Primary and secondary data was used. A sample of 416 households were targeted (n =208 who had adopted biogas and n = 208 who had not adopted). Random sampling was used to select households using the transect line survey of every fifth household for each of the four wards in each of the four sub counties. The method was preferred because as previously noted it greatly reduces bias and was more efficient (Burnham *et al,* 1985; Pearson and Ruggiero, 2003; Buckland *et al*., 2007).

Quantitative data was analyzed using descriptive statistics such as frequencies, percentages and averages while Chi-square test ($P \leq 0.05$) was used to analyze qualitative data.

5.4 Results and Discussion

Respondents' knowledge, attitudes and practices on adoption of biogas and its governance (Table 8) indicate that 87.64% of the respondents knew about biogas and its usefulness. Only minority (21%) of the sample population were aware of the regulatory legislation while majority (85%) did not comply with the regulation.

Table 8: Respondents' knowledge, attitudes and practices on biogas and environmental governance (n=416)

Parameter	Yes (positive) (%)	No (negative) (%)
Knowledge of biogas	87.64±2.11[a1]	12.36±2.17[b2]
Awareness of current legislation	21.2±1.62[a2]	78.8±1.67[b2]
Compliance to laws and policies	84.7±2.05[a1]	15.3±2.11[b2]

[a-d] Different letters and numbers in the same row and column differ statistically by Chi-square, P<0.01; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice

These findings point towards lack of public participation during legislation of biogas, and the need to create awareness to promote compliance with lawsand policies on biogas governance (Markell, 2004; Muigua and Musyimi, 2008; Murombo, 2008; Du Plessis, 2008; Wakiaga, 2018). This could be enhanced through the County Governments Act, 2012, which strongly advocates for laws and regulations that allow for unequivocal citizen participation in environmental governance. At the national level lack of awareness could affect understanding of the connection between adoption of clean energy and a clean, healthy environment, which is advocated for everyone residing in Kenya (EMCA, 1999). The finding on low compliance agrees with others because enforcement and implementation of laws, regulations, policies and regulatory frameworks on clean energy and the environment has been a challenge in many societies (Holley, 2017). Results in Table 9 indicate that biogas adoption in Kiambu was low

(25%) and that majority of those adopting the biogas technology (98%) are not organized into associations. There was also moderate (50%) institutional support for biogas adoption.

Table 9: Institutional support and member association supporting adoption of biogas technology in Kiambu (n=416)

Parameter	Yes (positive) (%)	No (negative) (%)
Practicing biogas	24.7 ± 1.44^{a1}	75.3 ± 1.49^{b2}
Membership to biogas association	2.35 ± 6.242^{a2}	97.65 ± 2.785^{b2}
Institutional support	50.6 ± 1.89^{b1}	49.4 ± 1.90^{b1}

$^{a\text{-}d}$ *Different letters and numbers in the same row and column differ statistically by Chi-square, $P<0.01$; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice*

These findings are unexpected given that there is value in belonging to biogas users' associations. Advantages of belonging to biogas users' associations have been well documented (BAG, 2017; WBA, 2017). This can be explained by the fact that the low awareness and adoption rate reported in Table 8 and Table 9 contributed to these findings. Thus, as adoption increases, more biogas users' associations will emerge to lobby for support and facilitation in biogas technology. The institutional support cited was some regulation from Kiambu County by-laws and the National government regulations through the Ministry of Energy and Petroleum in liaison with the County Government of Kiambu. However opportunities exist for capacity building.

Results in Table 10 show that willingness to adopt biogas technology was high in Kiambu (90%) and the felt value addition in being members of biogas user associations was also high (95%). However the regulation process was weak (21%).

Table 10: Factors for enhancing implementation of regulatory instruments on adoption of biogas in Kiambu (n=416)

Parameter	agree (positive) (%)	disagree (negative) (%)
Willing to adopt biogas	89.7 ± 2.43^{a1}	10.3 ± 2.38^{b2}
Value addition in associations	95.29 ± 1.29^{a1}	4.71 ± 1.48^{b2}
Regulation of biogas is strong	21.18 ± 1.74^{a2}	78.82 ± 1.97^{b1}

$^{a-d}$ *Different letters and numbers in the same row and column differ statistically by Chi-square, P<0.01; Adopted: respondents who had adopted biogas; Not adopted: respondents of the contrary practice*

These findings are unique to Kiambu County. The county has been documented to have good laws meant to protect the environment but not implemented (CIDP, 2013-2017). Probably there is a disjoint in the legislation leading to lack of stakeholder involvement and participation as spelt out in the EMCA Act of 1999 (Mireri and Letema, 2012). What gives hope is the residents' willingness to adopt the technology as a source of clean energy, which automatically would enhance regulation in sustainable social-economic progress (Bolinger *et al.*, 2001). More critically, these frameworks would be enforced for the desired invaluable benefits to man and the environment and the County and National governments (Augusto and Ioris, 2014).

5.5 Conclusion and Recommendations

There is weak regulation and low adoption of biogas technology in Kiambu. However potential exists for enhanced adoption of biogas especially through increased institutional and legislation support. There is also need for awareness creation on governance instruments and the need to address the capacity gaps existing.

CHAPTER SIX

6.0 Benefits of Adopting Biogas Technology in Kiambu County (International Journal of Innovative Research and Knowledge, 3 (3): 87-92)

6.1 Abstract

There is a close relationship between clean energy, environmental health and human livelihoods. Thus as it becomes more significant for societies to adopt clean energy, it also becomes paramount to integrate this push based on perceived benefits for adoption. Fundamental challenges and opportunities exist for adoption of biogas technology in Kiambu County. This paper documents opportunities for enhancing biogas adoption based on perceived benefits. Data was collected from four sub counties of Kiambu using household surveys (n=40 for adopters and n=40 for non-adopters). Both adopters and non-adopters were aware of benefits of adopting biogas technology and pointed out environmental, social and economic benefits (n=80; $P \leq 0.05$; $X^2=84$). Adopters cited the improved farm fertility and clean environment through utilization of slurry from the biogas bio-digesters in farms (n=40; $P \leq 0.05$; $X^2=91$). All respondents indicated that adoption of biogas technology would help mitigate climate change (n=80; $P \leq 0.05$; $X^2=67$). All respondents also indicated that biogas reduces indoor pollution (n=80; $P \leq 0.05$; $X^2=92.4$). Biogas was indicated to offer the benefit of manure waste management (n=80; $P \leq 0.05$;$X^2=89.1$). Respondents stated that adoption of biogas would help save on time used to fetch firewood (n=80; $P \leq 0.05$; $X^2=94$). Biogas was highly rated on reliability (n=80; $X^2=67$) and efficiency (n=80; $X^2=60$). Adopting respondents indicated biogas is economical (n=40; $X^2=56$). All respondents cited the benefit of job creation (n=80; $X^2=53$). Incorporation of awareness of

perceived benefits could prove useful in co-designing and co-implementation of governance and management frameworks for biogas in Kiambu County and Kenya at large.

Key words: Biogas, benefits, adoption, Kiambu County

6.2 Introduction

Biogas is considered as a major source of clean energy (Karekezi *et al*., 2008; IEA, 2017; Kavisi *et al*., 2018). Biogas could contribute to a shift towards clean, reliable, affordable and sustainable forms of energy (Grübler and McDonald, 1996; Bolinger *et al*., 2001; Ploeg and Withagen, 2014; Richardson, 2016; Covert, *et al.,* 2016; IEA, 2017) and possibly allow for convenient transition from conventional to green energy (IFG, 2004; Hohmeyer and Bohm, 2015; Noseleit, 2018). Biogas could also lead to reduction of green house gas emissions that have led to global warming and climate change (Dincer and Rosen, 1998; Losey *et al*., 2006; Bradshaw, 2010; Das *et al.*, 2011; Lovins, 2012; Kozinski *et al*., 2016).

Despite the above stated reasoning for adoption of biogas, Kiambu County continues to experience low adoption of this technology (Kavisi *et al*., 2018). The paper documents respondents' perceived benefits that could be utilized to enhance adoption of biogas technology in Kiambu. Once used as a basis for adoption of the technology, sustainable adoption could contribute towards achieving Sustainable Development Goals and most notably Goal Number 7 that focuses on access to affordable, reliable, sustainable and modern energy for all (UN, 2015).This would also help address the gap between energy supply and demand, shortcomings of conventional forms of energy as well as the increasing desire for clean energy in Kiambu. Since there is a close-knit relationship between clean energy and sustainable environmental management, adoption of biogas would have a significant contribution to environmental health.

6.3 Materials and Methods

The conceptual framework (Figure 1) considered benefits of biogas expected to spur the community's interest to make the people adopt the technology. Eighty (80) respondents participated in the survey (n =40 of them had adopted biogas and n = 40 had not adopted biogas). A previously described method (Kavisi *et al*., 2018) was used to collect data using a questionnaire with open and closed questions. Interviews, observation and focused group discussions (FGD) were utilized. Primary and secondary data was used and random sampling was done by selecting respondents using line transects. Every fifth household was sampled along the transect lines for each of the four wards in the sub-counties of Githunguri, Lari, Limuru and Ruiru. Quantitative data was analysed using descriptive statistics such as frequencies, percentages and averages while Chi-square test ($P \leq 0.05$) was used to analyse qualitative data. Data collected emphasized on the respondents' benefits for adoption of biogas technology.

6.4 Results and Discussion

The results are presented in descriptive terms. Both adopters and non-adopters were aware of benefits of adopting biogas technology and pointed out environmental, social and economic benefits ($n=80$; $P \leq 0.05$; $X^2=84$).

6.4.1 Environmental Benefits

These benefits were mentioned by all respondents. Adopters cited the improved farm fertility and clean environment through utilization of slurry from the biogas bio-digesters in farms (n=40; $P \leq 0.05$; $X^2=91$). This agrees with Heegde and Sonder (2007) and Alayi *et al* (2016) who found out that slurry as a by-product of biogas brought positive changes in farms and farmers were satisfied with the outcome. Slurry helps to improve soil fertility because it is rich in nutrients and its nitrogen content is three times more than what is found in organic fertilizer (Gitonga, 1997). By increasing soil fertility, slurry removes the need to expand agricultural land in order to increase harvests (Heegde and Sonder, 2007). This benefit could be utilized to enhance biogas technology adoption in Kiambu for organic farming. These findings are also in agreement with Kebede *et al.,* (2016) who noted that making farmers aware of additional benefits of the technology other than biogas would encourage others to invest in this type of clean energy.

All respondents indicated that adoption of biogas technology would help mitigate climate change (n=80; $P \leq 0.05$; $X^2=67$). This agrees with previous authors who described biogas as a climate-friendly technology contributing low carbon energy mix (Alayi *et al.*, 2016; Mengistu *et al.*, 2016). This benefit could be incorporated for adoption through paid carbon credits within the REDD+ initiative (Githiru, 2016) to motivate more people to turn to biogas for additional income (NCCRS, 2010).

All respondents also indicated that biogas reduces indoor pollution (n=80; $P \leq 0.05$; $X^2= 92.4$). This agrees with the WHO 2018 report that biogas ensures homes are clean compared to when they were using wood and dung fuel. Kitchen conditions are improved and cases of indoor air pollution (IAP), respiratory infections, eye irritation, among others are reduced (Islam and Hossein 2014; Inda and Moronge, 2015; Shane and Gheewala, 2016; WHO, 2018).

Biogas was indicated to offer the benefit of manure waste management (n=80; $P\leq 0.05$; $X^2=89.1$). This was in agreement with others who indicated effective and strategic waste management approach through use of bio-digesters (Fiorese and Guariso, 2012; Avery *et al.*, 2014). By using manure waste to generate clean energy, the degree of soil and water contamination is reduced significantly and this allows for agricultural activities to take place while at the same time minimizing cases of water-borne diseases (WHO, 2018).

6.4.2 Social Benefits

Respondents stated that adoption of biogas would help save on time used to fetch firewood **(**n=80; $P\leq 0.05$**;** $X^2=94$). As reported previously women and girls fetch firewood for their homes and biogas would save on that time (Maloy *et al.*, 1986; Muchiri, 2008). This could be argued to lead to higher household productivity since women and girls undertake the most household chores (UNIDO, 2009; Alayi *et al*., 2016).

Biogas was highly rated on reliability (n=80; $X^2=67$) and efficiency (n=80; $X^2=60$). As reported by Shane and Gheewala (2016), compared to firewood or charcoal, biogas lights with a single turn of the knob on the burner and once it is put on, it does not require constant attention or blowing to keep the fire burning instead it burns because the gas is continuously pushed by pressure from the bio-digester through pipes up to the burner.

6.4.3 Economic Benefits

Adopting respondents indicated biogas is economical compared to wood and fossil fuels (n=40; X^2=56). Gwavuya *et al*. (2012) observed that adoption of biogas technology enables households to make substantial savings on their energy consumption and saves also on other household expenses. All respondents cited the benefit of job creation (n=80; X^2=53). Others have reported how biogas could enhance job creation through fuel for vehicles and also in industries (Kennes and Veiga, 2013; Bhatia, 2014; Mengistu *et al*., 2015; Feroldi *et al.*, 2016; Singhal *et al*., 2017).

6.5 Conclusion and Recommendations

There are perceived benefits of adoption of biogas technology in Kiambu County. The perceived benefits could be utilized to enhance acceptance of the technology and address the reported existing challenge of low adoption of biogas in Kiambu County (Kavisi *et al*., 2018). Incorporation of awareness of such benefits could prove useful in co-designing and co-implementation of governance and management frameworks for biogas in Kiambu County and Kenya at large.

CHAPTER SEVEN

7.0 General Discussion, Conclusion and Recommendations

7.1 Discussion

The study has observed that adoption of biogas technology in Kiambu County is significantly dependent upon local demographic factors and biogas technology governance instruments. It has also been observed that a significant number of residents in Kiambu recognize the potential benefits of adopting biogas technology.

Although men were the decision makers for the household as far as adoption of biogas technology was concerned (Wawa, 2012; Mengistu *et al*., 2016), it was noted that women perform most of the work regarding the biogas plant in terms of preparing feedstock, feeding the bio-digester, cleaning and handling slurry as was also found out by Berhe *et al*., (2017). This finding can be positively utilized to persuade the household head (men) to increase adoption through awareness creation within women groups.

The knowledge, attitudes and practices (KAP) among adopters varied depending on such factors as level of education and social status (Obwogi, 2016). Education can be utilized to raise awareness of issues affecting biogas technology for its adoption in Kiambu (Bucciarelli *et al*., 2010; Riddell and Song, 2012). With very few exceptions, all adopters in Kiambu were practicing dairy farming from which they derived feedstock for production of biogas. Thus, decisions for increasing adoption of the technology should target such (Mengistu *et al.*, 2016). Most of the respondents were aware of biogas but very few knew about legislation governing green energy and environmental governance of which many of them did not comply with. This was an indication of low levels of awareness regarding regulatory frameworks yet they were critical in adoption of biogas technology. This could also be due to poor enforcement of existing legislation which in turn has encouraged people to continue using forms of energy that were not environment-friendly (Markell, 2004; Muigua and Musyimi, 2008; Murombo, 2008; Du Plessis, 2008; Wawa and Mwakalila, 2017; Wakiaga, 2018). Poor enforcement of legal instruments has also led to ecosystem degradation characterised through such acts as careless disposal of waste, pollution and destruction of water catchment areas (CIDP, 2013-2017; CKG, 2017).This is in fact a trend in many countries having faced challenges from different quarters when it comes to enforcing environmental legislation on clean energy regulations (Holley, 2017).

Biogas users' associations could be encouraged as an integral aspect in governance of biogas because members' sharing ideas of mutual interest would benchmark on best practices as well as research and development on emerging issues in this sub-sector (BAG, 2017; EBA, 2017). This was also expressed by respondents who acknowledged the importance of these associations but very few of them had registered as members (Gitonga, 1997; Heegde and Sonder, 2007; EBA, 2017). Similarly networking can help adopters get in touch with organisations like the Global Environment Fund (GEF) that could assist them get funds for improving gas production and management and even earn carbon credits for their efforts. At the moment farmers who have adopted biogas technology are doing so on individual basis and hence there is no synergy or forum that can advocate for their interests. However, this gap can be filled by adopters coming together to form associations that would bring mutual benefits to them.

Benefits that members gain by belonging to these associations can help in enhancing awareness about biogas which would then aid in increasing levels of adoption of the technology in Kiambu County and Kenya as a whole. Technologies that bring hitherto non-existent benefits tend to attract many people and diffuse relatively faster within society (OECD, 1998; Omwansa, 2009; Manali, 2014; OECD, 2017; Kumar and Sundarraj, 2018).Promotion of these associations would most likely aid in higher adoption of biogas technology in Kiambu County.

Benefits attributed to adoption of biogas in Kiambu could be utilized to up-scale its production. Reducing gender-based energy burdens on women, improving kitchen conditions, reliability, saving on energy expenses and general convenience are other key benefits that can be utilized to increase adoption of biogas as a clean form of energy as has been noted by others (UNIDO, 2009; Islam and Hossein, 2014; Inda and Moronge, 2015; Shane and Gheewala, 2016). Promotion of biogas technology is one of the strategies of ensuring universal access to modern energy services in line with Kenya's Sustainable Energy for All initiative (MOEP, 2016) and the UN's Sustainable Development Goals (UNDP, 2015).

Demographic factors play a significant role in people's decision to adopt biogas technology as was also noted by other scholars. However unlike some of the studies, this study observed that in order to accelerate adoption of biogas technology in Kiambu County, focus should be on enhancing the people's understanding of laws, regulations and policies that promote use of green energy for sustainable development as well as those that advocate for environmental governance.

In this way the community would know that they have a role to play in promoting green energy and safeguarding the environment.

Legal and policy gaps in green energy and environmental governance ought to be addressed as a strategy of enhancing adoption of biogas technology. Of critical importance is also to ensure that the laws are implemented so as to promote sustainable development in environmental, social and economic realms. Legal instruments on green energy can positively influence the community's attitude towards biogas leading to increased access to affordable energy, a clean environment, creation of employment opportunities, among others in Kiambu County and Kenya as a whole.

7.2 Conclusion

The following conclusions can be drawn from this study:

- ✓ Demographic factors played a significant role in determining adoption of biogas technology in Kiambu County.
- ✓ Governance of biogas technology in Kiambu County affected its adoption.
- ✓ There were perceived benefits in adopting biogas technology in Kiambu County.

7.3 Recommendations

From the above conclusions, the following recommendations are suggested for policy makers:

- There is need to consider the underlying local demographic factors that influence adoption of biogas in any policy decisions made regarding adoption of the technology.
- There is need for public participation through co-drafting and co-implementation of governance instruments that regulate biogas technology.
- Biogas technology could be up-scaled through awareness creation of its perceived benefits.

CHAPTER EIGHT

8.0 References

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CHAPTER NINE

9.0 Appendices

9.1 Questionnaire - Adopters

<u>Section A</u>

1. Serial No…………………….. ………… Date……………………………………..

2. Address/Location………………………………………………………………......

3. Name of interviewer………………… …………... ………………………………..

4. Signature…………………………..

5. Name of respondent………………………………………………………………….
6. .Gender

a. Male
b. Female

<u>Section B</u>

<u>Demographic Characteristics and Social Economic Status</u>

7. Gender of Household Head (please tick one)

a. Male ( )

b. Female ( )

8. Kindly state the age group of the house household head (please tick one)

   a. 20 – 30 years ( )
   b. 30 – 40 ( )
   c. 40 – 50 ( )
   d. 50 – 60 ( )
   e. Over 60 ( )

9. What is your family size? (persons supported by the household head)…………….

10. Please state the highest level of education of the household head……………………...

11. Kindly state occupation of the household head (please tick one)

   a. Farming ( )
   b. Business ( )
   c. Formal employment ( )
   d. Other ……………….

12. Kindly state your average monthly income (please tick one)

   a. a. < 10,000 ( )
   b. b. 10,000 – 20,000 ( )
   c. c. 20,000 – 30,000 ( )
   d. 30,000 – 40,000 ( )
   e. 40,000 – 50,000 ( )

f. f. Over 50,000 ( )

13. Do you own land? (please tick one)

a. Yes

b. No

14. If “yes”, what is the size? (in acres)………………………………………………

15. Do you own cattle (please tick one)

a. Yes

b. No

If “yes”, how many? ………………..

Section C

Energy Resources in Kiambu County

16. What are the sources of energy available in your household/institution?

a. Charcoal ( )

b. Firewood ( )

c. Kerosene ( )

d. LPG Gas ( )

e. Electricity ( )

17. When did you start using biogas?

....

18. Is your biogas plant currently in working condition?

a. Yes ( )

b. No ( )

19. If the answer is "no", please tick one of the following:

a. It broke down ( ) d. Lack of spare parts ( )

b. Lack of maintenance ( ) e. No funds for repair ( )

c. Poor workmanship ( ) f. Other…………………….. ( )

20. For what purposes do you use the biogas?

………………………………………………………………………………………

………………………………………………………………………………………

21. What prompted you to adopt use of biogas?

………………………………………………………………………………………

22. What was your major source of energy before adoption of biogas technology?

………………………………………………………………………………………

………………………………………………………………………………………

23. Where were you sourcing the materials for that energy? (Distance from your home/institution)……………………………………………………………

24. What raw materials do you use in the production of biogas?

……………………...

………………………………………………………………………………

25. Please give a breakdown in terms of quantity of waste used

…………………………………………………………………………………….

……………………………………………………………………………………..

……………………………………………………………………………………..

26. How much did you use to install the biogas plant?

....

………………………………………………………………………………………

27. Name some advantages you have experienced since adoption of biogas……………………………………………………………………………….

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

28. In your opinion, what are the advantages of using biogas?

…………………………………………………..

………………………………………………………………………………………

………………………………………………………………………………………

29. Are there any challenges in production and use of biogas?

……………………………………………………………………………………….

………………………………………………………………………………………

30. If your answer s "yes", please explain

……………………………………………………………………………………….

………………………………………………………………………………………

31. Describe the support (if any) that you get from the National/County Governments in utilizing biogas technology?

……………………………………………………………………………………….

……………………………………………………………………………………….

……………………………………………………………………………………….

32. Do you get any support from the firm that installed your biogas plant?

....

33. If your answer is “yes”, please explain…………………………………………………………………………..

……………………………………………………………………………………….

……………………………………………………………………………………….

34. In your opinion, why is there low uptake of biogas technology in Kiambu County and what could be done to improve it?

…………………………………………………………………………………………

9.2 Questionnaire – Non-adopters

<u>Section A</u>

1. Serial No…………………….. …………. Date……………………………………...
2. Name of interviewer…………………   Signature…………………………………
3. Address/Location……………………………………….
4. Name of respondent…………………………………….
5. Gender

a. Male

b. Female

6. **<u>Section B</u>**
7. **<u>Demographic Characteristics and Social Economic Status</u>**
8. Gender of Household Head   (please tick one)
9. Male
10. Female
11. Kindly state the age group of the household head (please tick one)

    a.20 – 30 years ( )   b. 30 – 40 years ( )   c. 40 – 50 years ( )

    d. 50 – 60 years ( )   e. Over 60 years ( )

12. What is your family size (persons supported by household head) ……………
13. Please state the highest level of education of the household head……………………………………………………………………………...
14. Kindly state occupation of household head (please tick one)

a. Farming   ( )

b. Business ( )

c. Formal employment ( )

d. Other ………………

15. Kindly state your average monthly income (please tick one)

a. < 10,000 ( )

b. 10,000 – 20,000 ( )

c. 20,000 – 30,000 ( )

d. 30,000 – 40,000 ( )

e. 40,000 – 50,000 ( )

f. Over 50,000 ( )

16. Do you own land? (please tick one)

a. Yes

b. No

17. If “yes”, what is the size in acres? ....

18. Do you own cattle? (please tick one)

a. Yes

b. No

If “yes”, how many? ………….

19. If “no”, kindly give reasons

a. Lack of space ( )

b. Lack of animal feeds ( )

c. Insufficient funds ( )

d. Too labour intensive to rear ( )

e. Other ( )

Section C

Energy Resources in Kiambu County

20. What are the sources of energy available in your household/institution?

a. Charcoal ( )

b. Firewood ( )

c. Kerosene ( )

d. LPG Gas ( )

e. Electricity ( )

21. Have you ever heard of biogas? …………………………………………………

22. If your answer is "yes", how did you learn about it?

…………………………………………………………………………………………

………………………………………………………………………………………..

…………………………………………………………………………………………

23. Why haven't you adopted the use of biogas?

a. ………………………………………………………………………………

b. ………………………………………………………………………………

c. ………………………………………………………………………………

d. ………………………………………………………………………………

e. If impediments to your adoption of biogas were removed, would you adopt the technology?

………………………………………………………………………………….

…………………………………………………………………………………

f. Do you think there are advantages in using biogas?

....

....

....

....

....

24. What is your major source of energy?

…...

25. Where do you source the materials for that energy? (Distance from your home)…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

26. In your opinion, why is there low uptake of biogas technology in Kiambu County and what could be done to improve it?

……………………………………………………………………………………..

……………………………………………………………………………………..

9.3 Questionnaire – Governance

<u>Section A</u>

1. Serial No…………………………………… Date…………………………………..
2. Name of interviewer……………………….. Signature…………………………….
3. Address/Location/Sub County………………………………………………………
4. Name of respondent…………………………………………………………………
5. Gender

a. Male

b. Female

<u>Section B</u>

<u>Demographic Characteristics and Social Economic Status</u>

6. Gender of Household Head

a. Male

b. Female (please tick one)

7. Kindly state the age group of the household head (please tick one)

a. = 20 – 30 years ( ) b. = 30 – 40 ( ) c. = 40 – 50 ( )

d. = 50 – 60 ( ) e. = 60 – 70 ( ) f. Over 60 ( )

8. What is your family size (persons supported by household head) ……………

9. Please state the highest level of education of the household head………………………………………………………………………………

10. Kindly state occupation of household head (please tick one)

c. Farming ( )

d. Business ( )

c. Formal employment ( )

d. Other …………… ( )

11. Kindly state your average monthly income (please tick one)

a. < 10,000 ( )

b. 10,000 – 20,000 ( )

c. 20,000 – 30,000 ( )

d. 30,000 – 40,000 ( )

e. 40,000 – 50,000 ( )

f. Over 50,000 ( )

12. Do you own land? (please tick one)

a. Yes ( )

b. No ( )

13. If "yes". what is the size in (acres)……………………………………………...

14. Do you own cattle? (please tick one)

a. Yes ( )

b. No ( )

15. If "yes", how many? ………….

16. If "no", kindly give reasons

a. Lack of space ( )

b. Lack of animal feeds ( )

c. Insufficient funds ( )

d. Too labour intensive to rear ( )

e. Other ( )

Section C

Energy Resources in Kiambu County

17. What are the sources of energy available in your household/institution?

a. Charcoal ( )

b. Firewood ( )

c. Kerosene ( )

d. LPG Gas ( )

e. Electricity ( )

f. Biogas ( )

18. Have you ever heard of biogas? …………………………………………………

19. If your answer is "yes", how did you learn about it?

…………………………………………………………………………………………

20. Are you aware of any government regulations that promote biogas…………….

21. If your answer is "yes", please give an example (s)

a. …………………………………….

b. …………………………………….

22. Do you know that you have a right to a clean and healthy environment?

a. Yes ( )

b. No ( )

23. Are you aware that you have a duty to safeguard and enhance the environment?

a. Yes ( )

b. No ( )

24. Are you aware of any government agency that deals with green energy?

a. Yes ( )

b. No ( )

25. What measures has the government put in place in promotion of green energy in Kiambu County?

a. ……………………………………………………………………………………..

b. ……………………………………………………………………………………..

c. ……………………………………………………………………………………..

26. Do you know of any laws or policies on green energy?

a. Yes ( )

b. No ( )

27. What is the level of compliance of government regulations and policies on green energy in Kiambu County?

28. How effective have been the legal and institutional frameworks in enhancing the use of green energy?

a. Very effective ( )

b. Moderate ( )

c. Ineffective ( )

d. Not sure ( )

29. What has been the impact of the government's green energy policies on the environment in Kiambu?

a. ……………………………………………………………………………………….

b. ………………………………………………………………………………………..

c. ………………………………………………………………………………………..

d. ……………………………………………………………………………………….

30. In your opinion, what strategies can the government employ in order to scale up production and use of sustainable, carbon-free energy?

a. …………………………………………………………………………………………

b. …………………………………………………………………………………………

c. ………………………………………………………………………………………….

d. ………………………………………………………………………………………….

31. In what ways can the government effectively engage citizens in the promotion of green energy?

a. ………………………………………………………………………………………….

b. ………………………………………………………………………………………….

c. …………………………………………………………………………………………..

d. ………………………………………………………………………………………….

32. How would Kiambu County benefit from enhanced adherence and enforcement of government policies on green energy?

a. A clean environment

b. Increased access to affordable energy

c. Low cost of energy

d. Creation of employment opportunities

33. What has been the major challenge in government efforts to promote green energy in Kiambu?

a. Lack of awareness ( )

b. Inadequate funds to implement projects ( )

c. Human resource challenges ( )

d. Disinterest in green energy ( )

e. Corruption ( )

9.4 Questionnaire - Agencies

<u>Section A</u>

1. Serial No…………………….. …………. Date………………………………………
2. Name of interviewer…………………….. Signature…………………………………
3. Name of interviewee…………………………………………………………………..
4. Address/Location……………………………………………………………………
5. Government Ministry/Agency/Company

   ………………………………………………………………………………………..
6. What are the sources of energy available to households and institutions in Kiambu County?

   a. ………………………………………………………………………………..
   b. ………………………………………………………………………………..
   c. ………………………………………………………………………………..
   d. ………………………………………………………………………………..

7. What is the level of awareness of biogas technology in Kiambu County?

a. <10%

b. 20%

c. 30%

d. 40%

e. >50%

8. What is the extent of biogas production and use in Kiambu County?

   a. ………………………………………………………………………………………..

   b. ………………………………………………………………………………………..

   c. ………………………………………………………………………………………..

   d. How would you describe the attitude of the locals towards this form of energy?

   ………………………………………………………………………………………..

   ……………………………………………………………………………………….

   ……………………………………………………………………………………….

9. If the attitude is contrary to the promotion of green energy, how can it be changed?

   a. ……………………………………………………………………………………..

   b. ……………………………………………………………………………………..

   c. ……………………………………………………………………………………..

10. What raw materials could potentially be used in production of biogas in Kiambu County?

   a. ………………………………………………………………………………………

   b. . …………………………………………………………………………………….

   c. ………………………………………………………………………………………

11. What are the challenges to the adoption and use of biogas in Kiambu County?

   a. ……………………………………………………………………………………..

   b. ……………………………………………………………………………………..

   c. ……………………………………………………………………………………..

12. What can be done to maximize on the potential of biogas production and utilization in Kiambu County?

    a. ……………………………………………………………………………………..
    b. ……………………………………………………………………………………..
    c. ……………………………………………………………………………………..

13. What intervention measures have been put in place to enhance production and utilization of biogas in Kiambu County?

    a. ……………………………………………………………………………………..
    b. ……………………………………………………………………………………..
    c. ……………………………………………………………………………………..

14. What would you consider to be the advantages of using biogas?

    a. ……………………………………………………………………………………..
    b. ……………………………………………………………………………………..
    c. ……………………………………………………………………………………..

<u>Section B</u>

TYPES OF WASTE GENERATED IN KIAMBU COUNTY PER ANNUM

15. Kindly give the amount of waste (in tons/litres) that is generated in Kiambu County every year.
16. Domestic/household waste ………………………………..
17. Municipal waste:

a. Solid………………………………………...

b. Liquid…………………………………….

c. Human waste………………………………..

d. Effluent from slaughterhouses………………

18. Animal waste such as:

a. Cow dung…………………………………...

b. Pig dung…………………………………….

c. Poultry waste………………………………..

19. Agricultural waste/bio-waste/organic residues from :

a. Coffee (pulp) ……………………………..

b. Maize silage……………………………….

c. Tea………………………………………….

d. Horticulture……………………………….

e. Waste from flower farms…………………

<u>Section C</u>

TREE COVER IN KIAMBU COUNTY

23. What is the amount of tree cover in Kiambu County?..

24. How much tree cover is lost per year through use of wood fuel? …………………………….

…………………………………………………………………………………………………

25. How much tree cover is likely to be saved per year in Kiambu County by use of biogas?

a. <10%

b. 20%

c. 30%

d. 40%

e. >50%

26. What is the approximate annual reduction in Green House Gas emissions through use of biogas in Kiambu County? (Please tick one)

a. <10%

b. 20%

c. 30%

d. 40%

e. >50%

27. Kindly add any other information that you think might be useful to this study

…………………………………………………………………………………………………

…………………………………………………………………………………………………

28. What is the future of biogas technology in Kiambu County?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

9.5 Key Informants

9.5.1 Government/Public officials/agencies/institutions

Deputy County Commissioner, Lari sub-county

Deputy Director, Kenya Forest Service

Director of Environment, Kiambu County

Energy Regulatory Commission

Gender Development Officer, Kiambu County

Gender Development Officer, Lari sub-county

Kagwe Girls High School, Lari sub-county

Kenya Electricity Generation Company

Kenya Nuclear Electricity Board

Kiambu Level 4 Hospital

Librarian, Kenya National Bureau of Statistics

Livestock Development Officer, Kiambu County

Livestock Development Officer, Limuru Sub-County

Manager, Field Station, University of Nairobi

Ministry of Energy and Petroleum

9.5.2 Non- Governmental/ Community Based Organisations

Dagoretti Slaughterhouse, Kikuyu sub-county

Githunguri Dairy and Community SACCO Limited

Kentainers Limited – they manufacture bio-digesters made of polyethylene

Kenya Assemblies of God Church, Kamirithu Village, Limuru sub-county

Limuru Biogas Users' Association

Rift Valley Women Group, Lari sub-county

Sustainable Energy Strategies (biogas contractors)

Takamoto Biogas Company, Githunguri

Thogoto Home for the Aged, Kikuyu sub-county

Visionary Empowerment Programme

9.6 Introduction letter.

UNIVERSITY OF NAIROBI
COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES
WANGARI MAATHAI INSTITUTE FOR PEACE AND ENVIRONMENTAL STUDIES

OFFICE OF THE DIRECTOR

Telephone: 020-2506448, 0788526473
Email : wmi@uonbi.ac.ke
Website : wmi.uonbi.ac.ke

P.O Box 30197- 00100
Nairobi,
Kenya .

Ref: **A82/99407/2015**

October 5, 2016

TO WHOM IT MAY CONCERN

RE: INTRODUCTION LETTER FOR KENNETH KIVISI MBALI A82/99407/2015

Mr. Kenneth Kivisi Mbali is a PhD student at Wangari Maathai Institute for Peace & Environmental Studies. He is currently undertaking research on **'Strategies of up scaling Production and Management of Biogas in Kiambu County, Kenya'.**

He will be working in Kiambu County collecting data for his research project.

Any assistance rendered to him will be highly appreciated

Yours Sincerely,

PROF. HENRY M. MUTEMBEI
DIRECTOR
WANGARI MAATHAI INSTITUTE FOR PEACE &
ENVIRONMENTAL STUDIES

VISION
Excellence in experiential learning transformational community outreach and research for sustainable environment and cultures of peace

9.7 Research Permit

THIS IS TO CERTIFY THAT:
MR. KENNETH KIVISI MBALI
of UNIVERSITY OF NAIROBI, 0-100
Nairobi,has been permitted to conduct
research in *Kiambu County*

on the topic: *STRATEGIES OF UP SCALING PRODUCTION AND MANAGEMENT OF BIOGAS IN KIAMBU COUNTY, KENYA*

for the period ending:
13th June,2018

Permit No : NACOSTI/P/17/73415/17349
Date Of Issue : 14th June,2017
Fee Recieved :Ksh 2000

Applicant's Signature

Director General
National Commission for Science, Technology & Innovation

9.8 Research authorization

NATIONAL COMMISSION FORSCIENCE, TECHNOLOGY ANDINNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
Fax: +254-20-318245,318249
Email: dg@nacosti.go.ke
Website: www.nacosti.go.ke
When replying please quote

9th Floor, Utalii House
Uhuru Highway
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/17/73415/17349**

Date: **14th June, 2017**

Kenneth Kivisi Mbali
University of Nairobi
P.O. Box 30197-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Strategies of up scaling production and management of Bigas in Kiambu County, Kenya,"*** I am pleased to inform you that you have been authorized to undertake research in **Kiambu County** for the period ending **13th June, 2018.**

You are advised to report to **the County Commissioner and the County Director of Education, Kiambu County** before embarking on the research project.

On completion of the research, you are expected to submit **two hard copies and one soft copy in pdf** of the research report/thesis to our office.

GODFREY P. KALERWA MSc., MBA, MKIM
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Kiambu County.

The County Director of Education
Kiambu County.