ANALYSIS OF BIOGAS TECHNOLOGY FOR HOUSEHOLD ENERGY, SUSTAINABLE LIVELIHOODS AND CLIMATE CHANGE MITIGATION IN KIAMBU COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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DEDICATION

This piece is especially dedicated to my lovely son, Mathew Austen! I wish him all my blessing as he grows up and venture into the world of academics!

To my mom and dad for their steadfast support in my education, and to my late brother George! Rest in peace bro!

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ABBREVIATIONS AND ACRONYMS

ADB:	Asia Development Bank
AEPC:	Alternative Energy Promotion Center
ALCS:	Action Learning Case Studies
ANOVA:	Analysis of Variance
BSP:	Biogas Support Programme
CARMATEC:	Centre for Agricultural Mechanization and Rural Technology
CH_3CO_2H:	Acetic Acid
CH_4:	Methane
CDM:	Clean Development Mechanism
C/N:	Carbon Nitrogen Ratio
CNS:	Central Nervous System
CO_2:	Carbon Dioxide
DFID:	Department for International Development (UK)
DEFRA:	Department of Food and Rural Affairs (of the UK)
EPA:	Environment Protection Agency (of the US)
ERS:	Economic Recovery Strategy
FAO:	Food and Agriculture Organization
FiT:	Feed in Tariff
GDP:	Gross Domestic Product
GHGs:	Green House Gases
GOK:	Government of Kenya
GTZ:	German Organization for Technical Cooperation
GWP:	Global Warming Potential

IEA:	International Energy Agency
HDR:	Human Development Report
HH:	Household
$H_{2:}$	Hydrogen
H_2S:	Hydrogen Sulphide
HRT:	Hydrolic Retention Time
IPCC:	Intergovernmental Panel on Climate Change
KENBIM:	Kenya National Biogas Model
KENDBIP:	Kenya National Domestic Biogas Programme
KENFAP:	Kenya National Federation of Agricultural Producers
KNBS:	Kenya National Bureau of Statistics
KVIC:	Khadi and Village Industries Commission
LCFA:	Long Chain Fatty Acids
LCPDP:	Least Cost Power Development Plan
LPG:	Liquefied Petroleum Gas
MDGs:	Millennium Development Goals
NCCRS:	National Climate Change Response Strategy
N_2O:	Nitrous Oxide
NH_3:	Ammonia
NH_4^+:	Ammonium Ion
NO_3:	Nitrates Ion
PICs:	Products of Incomplete Combustion
PVC:	Poly vinyl chlorides
RETs:	Renewable Energy Technologies

SCODE:	Sustainable Community Development Services
SLA:	Sustainable Livelihood Approach
SLF:	Sustainable Livelihood Framework
SNV	Netherlands Development Organization
SPSS:	Statistical Program for Social Scientists
SRT:	Solids Retention Time
SSA:	Sub-Saharan Africa
UNCED:	United Nations Conference on Education and Development
UNDP:	United Nations Development Programme
UNEP:	United Nations Environmental Programme
UNFCCC:	United Nations Framework Convention on Climate Change
USDA:	US Department of Agriculture
UN-Energy:	United Nations Inter-agency Mechanism on Energy
VFAs:	Volatile Fatty Acids
WSSD:	World Summit on Sustainable Development

ABSTRACT

Domestic energy insecurity is a major threat to sustainable development in Sub Saharan Africa. Across the region, the fundamental role that firewood and charcoal plays in the social and economic welfare of many households cannot be overemphasized. This study aimed to assess the role of biogas technology in saving wood, mitigating green-house gases emissions, and in improving livelihoods in Kiambu County. Oral interviews, Focused Group Discussions, and Action Learning Case Studies were used on biogas adopter and non-adopter households. Participatory experimental research was carried out using selected farmers' installed bio-digesters of different designs and sizes. Cows were fed on nine different feed combinations and the biogas yield from these cows' dung tested for CH_4, CO_2 and H_2S contents. Gas was analyzed using portable Biogas Analyzer 5000 (Geo-tech UK). Fuel consumption and expenditure patterns was determined using household surveys. Carbon emission reduction was calculated from fuel consumption reduction with biogas use, and presented in CO_2 equivalent. Impact of the technology on livelihoods was analyzed using DFID (1999) framework on sustainable livelihoods. Data was analyzed using SPSS and SAS computer softwares. ANOVA revealed variation in gas quality from different cattle feeds. Descriptive statistics, tests of significance (t-tests and chi-square), and logistic regression were used to establish relationships between variables. There was high likelihood of biogas adoption with combination of independent variables age, education level, farm size and the number of cows owned. The technology showed great potential and real benefits for uplifting livelihoods. Significant financial savings were realized, with an average household saving about KShs 38, 676 (455 USD) annually upon shifting to biogas energy. Time savings (up to 5 hours weekly) was highly significant. Health of user households also improved tremendously with absolute reduction in smoke, and improved sanitation around the home environment. From a livelihood perspective, biogas energy technology gave adopter households' essential assets (human, physical, natural, social and financial) that enabled the households achieve positive livelihood outcomes. Among these assets, financial capital was probably the most resourceful. Wood consumption reduced immensely with biogas use. An approximate 303.8 metric tonnes firewood and 229.4 metric tonnes of wood from charcoal being conserved annually by biogas adopters. This combined helped mitigate approximately 1,079 tonnes of CO_2 equivalent from being emitted to the atmosphere. Type and size of digester did not significantly influence gas quality. However, gas quality was markedly influenced by cattle diet. A high protein feed, gave a combined optimal effect on CH_4 and CO_2 emissions. The highest methane yield was achieved from chicken dropping (64.2%) and fodder legumes (63.8%). The technology therefore offers a myriad of environmental benefits and is a major driver of livelihoods in Kiambu. Efforts and resources are needed to increase widespread adoption of the technology.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Biomass energy in the form of firewood, charcoal and crop residues plays a vital role in the basic welfare and economic activities in many Sub Saharan Africa (SSA) households, where they meet more than 90% of household energy needs (EIA, 2010; KIPPRA 2010). According to the US department of energy, about 75% of total wood harvested in SSA is used for cooking. Estimates indicate that the number of people using wood fuel will rise by more than 40% to about 700 million people in Africa by 2030 (EIA, 2006 & 2008). This scenario portends great danger for human and climate security, and constitutes a major roadblock to progress against poverty and growth of SSAs' economies.

In Kenya, reliance on wood fuel is particularly high, accounting for up to 95% of total energy consumption in rural households (GoK, 2012a; 2012b; van Beukering, 2007), and nearly 60% of urban dwellings (IEA, 2010). Access to alternative, clean and reliable energy systems in the rural areas is severely constrained with only an estimated 8% of the rural masses having access to electricity (EnDev, 2012, KIPPRA 2010), and other modern energy technologies (VENRO, 2009; IEA, 2009). Households' studies (Arnold *et al.*, 2006) show that wood remains the preferred form of domestic energy, largely because it doesn't require complex expensive equipment, it can be used in an open fire and can be procured often at no greater costs, than the labour of collecting it. For most households therefore, wood fuel remains the chief source of energy (UNDP, 2009), and a major switch to clean fuels in the near future seems unlikely (NEMA, 2005).

Even so, access to sustainable energy is very critical in the economic development of a nation (Okello *et al.,* 2013), because it touches basically all aspects of life; agriculture, health, industry and education, among others. For those living in extreme poverty, lack of access to reliable energy services dramatically limits opportunities. The vulnerability of the poor is worsened by recent challenges of climate change, and volatile energy prices (UN, 2012). Energy scarcity is arguably one of the challenges the world faces today in the quest for better livelihoods.

While it is acknowledged that wood-based fuels are important to the rural poor, its unsustainable extraction from forests and woodlands, and its combustion exacerbates deforestation and emits green house gases (GHGs), and other pollutants (Gustafson *et al*., 2009), contributing to detrimental public and environmental health (Okello *et al.*, 2013). Wood harvesting also leads to both regional and global environmental degradation (Kammen *et al.* 2007). For instance, the gazetted forest cover in Kenya has declined from 12% in the 60s to 6% in 2011 (GOK, 2011), substantially below the minimum recommended coverage of 10% (FAO, 2013, HDR, 2008). Deforestation poses a serious threat to environmental sustainability and is jeopardizing progress towards poverty and hunger eradication (UNDP, 2013). Dependence on forests worsens energy scarcity, and increases opportunity costs due to the additional time spent collecting wood (Amacher *et al*., 1999). This is especially true for women and children who spend many hours gathering wood fuel. These externalities arising from wood fuel dependence may hinder the achievement of millennium development goals (MDGs), of reducing child mortality, improving maternal health and achieving gender equality, as well as conserving the integrity of the environment.

Biogas energy production and use has been illustrated to have the potential to reduce wood fuel consumption, mitigate against climate change and reduce indoor air pollution (Smith *et al.* 2012). Biogas technology uses biological process to convert organic wastes into biogas (combustible mixture of methane and carbon dioxide) and high quality fertilizer. The technology is carbon neutral, and therefore does not add or remove CO_2 from the atmosphere. Potentially therefore, it is a significant and profitable way of mitigating global climate change. Biogas is generally considered to be a carbon-neutral source of energy because the carbon emitted during combustion was atmospheric carbon that was recently fixed by plants biomass, as opposed to the combustion of fossil fuels where carbon sequestered for millions of years is emitted into the atmosphere. Moreover, the technology is considered by many experts to be an effective tool for improving life, livelihoods, and public health in the developing world (KNDBP, 2011). Biogas energy is considered a sustainable solution to local energy needs, and provides significant benefits to human and ecosystem health. Unlike firewood, biogas burns without smoke, improving indoor air quality, and thus saving women and children from respiratory distress and ailments. Biogas can be used to generate electricity, prolonging the active hours of the day and enabling the family to engage in social or self-improvement activities, or to earn extra income.

Nonetheless, despite the huge potential for biogas, numerous efforts by the government and donor organizations since the energy crisis of the 1980s, to disseminate biogas technology, especially in rural Kenya has however not been able to achieve scale ((Walekhwa *et al.,* 2009). Most households have persistently continued to use wood fuel, with the resultant negative effects. Given the inter-related challenges of poverty and energy demand, climate change, indoor air pollution and human health, accelerated and large-scale dissemination of biogas technology is therefore now necessary more than ever before. The key energy challenges facing the country and the region is how to affordably produce high quality cooking gas and also how to widely disseminate biogas energy technologies

1.2 Problem Statement

In the greater Kiambu County, most households rely on wood fuel as the primary source of household energy (Githiomi *et al.,* 2011). Modern fuels such as liquefied petroleum gas (LPG) and electricity are expensive and only at the reach of Kenya rich, while the more friendly green energy such as wind-power and solar have not been sufficiently exploited (Karekezi and Kimani, 2009). As a consequence, more than 90% of households in this area continue to overly rely on wood fuel to meet their cooking and heating energy needs, and this has far-reaching environmental and health effects (UNEP, 2012). Over the years this high demand for wood fuel has put a lot of strain on the environment leading to destruction and disappearance of forests in the region, and by extension loss of carbon sinks and other ecosystem values and functions that emanate from trees. Besides, continued combustion of wood fuel in the area has contributed to indoor air pollution and increase in respiratory ailments among users, and this is attributed to excessive products of incomplete combustion (PICs) and smoke emissions in the poorly ventilated houses, common in the area. At the same time majority of area residents rear cattle, and hence huge quantities of dung are produced which emit massive fugitive methane gas into the atmosphere, exercabating global warming and climate change.

As an effort to counteract these environmental, public health and social problems arising from wood fuel combustion and use, and dung production, numerous efforts by several development organizations in Kenya, and the national government of Kenya (GoK) through the ministries of energy and agriculture, to introduce biogas technology in the area, to provide affordable, clean and sustainable domestic energy to the residents have not been successful (GoK, 2011). Only a small proportion of the area residents have adopted the technology (Pandey *et al.*, 2007). Majority of households (more than 90%) have persistently continued to cook with inefficient traditional wood fuel systems (Oduor, 2012)with consequent detrimental environmental effects (Kammen *et al.*, 2007),. Development and utilization of biogas; a modern and desirable eco-friendly form of appropriate technology remains low (Karekezi and Kimani, 2009; Pandey *et al.*, 2007) and its adoption is slow. The potential of this technology has thus remained untapped, and its socio-economic and environmental benefits have largely remained elusive. The reasons for this scenario remain unexplored.

It is not clear what factors motivate some households in Kiambu to adopt the technology while many others do not adopt. The question then that lingers is why is the adoption of this technology still low, and why are people not taking up the technology despite its enormous potential. Previous studies in the Country (Kenya) have shown that biogas technology have failed to achieve scale due to poor designs, poor dissemination strategies, farmer's socio-economic status and overall less favourable reputation (Shell Foundation, 2007; Mwirigi *et al.*, 2009; ABPP, 2013). It is also not examined how cattle management regimes (type of feed) affects the quality of biogas produced. The purpose of this study therefore was to identify the factors that influence adoption of biogas technology in typical households in Kenya, the impact of biogas use on livelihoods and the environment, and assess the effect of animal feeds on biogas quality.

1.3 Research Questions

This research was motivated by the need to understand the potential of biogas technology in rural settings of Kenya with regard to local livelihoods and climate change. The following broad questions were used to get useful insights into biogas technology.

i. Why do some households choose to adopt or not adopt biogas energy technology in rural Kiambu County?

ii. What are the social, economic and health benefits of adopting biogas technology at the household level, and how do these impact livelihoods in rural Kiambu?

iii. How does biogas energy production and use in Kiambu influence household energy supply, deforestation and carbon emissions?

iv. Does the type of cattle feed influence the concentration of CH_4 and CO_2 gases in biogas yield?

1.4 Research Hypotheses

i. There is significant association between household social economic factors and adoption of biogas technology.
ii. Adoption and use of biogas technology leads to significant improvement in household health, income, education and time savings.
iii. Household using biogas energy significantly reduces wood consumption and carbon emissions compared to non-adopters
iv. Feeding cattle with high nitrogen based feeds leads to production of high quality gas in terms of CH_4 concentration as compared to feeding with roughage.

1.5 Research Objectives

1.5.5 General Objective

The overall objective of the proposed study was to explore the factors influencing biogas adoption in Kiambu County, Kenya, and assess the contribution of the technology as a tool for improving livelihoods of rural communities and also for mitigating climate change.

1.5.2 Specific Objectives

The specific objectives were;

i. To identify and analyze factors influencing biogas energy adoption and utilization in Kiambu County,
ii. To determine the role and potential of biogas energy technology in improving the livelihoods of the area residents.

iii. To determine wood fuel savings and carbon emissions equivalent arising from adoption and use of biogas at the household level in Kiambu County.

iv. To determine methane and carbon dioxide concentrations in biogas yield arising from different cattle feed types.

1.6 Rationale and Significance

That energy is essential for economic and social development of a nation needs no further emphasis (Rambo, 2013). Kenya’s current development strategies are mapped out in its Vision 2030 policy. The ‘Vision’ identifies energy as one of the key infrastructural enablers, necessary for the realization of its objectives (GoK, 2007; 2012a). As the country aspires to be a middle income economy as envisaged in the ‘Vision’, it faces an enormous task of meeting energy needs, owing to the high expectations in growth to power the economy. The country therefore needs to come up with strategies and investment plans to secure sustainable supply of energy to meet the growing demand (Ministry of Energy, 2011; KIPPRA, 2010). Additionally, as Kenya undergoes devolution, County development plans requires information on up scaling of technologies such as biogas, for their energy strategies. Other counties could as well borrow a lease from Kiambu. In as much, the Climate Change Secretariat at the Ministry of Environment; the National Communications to the UNFCCC Secretariat would find the results of this study useful in terms of reduced green house gases emissions.

Moreover, energy is central to sustainable development and poverty reduction efforts, since it affects all aspects of development; social, economic and environment, including livelihoods, access to water, agricultural productivity, health, population levels, education and gender issues. Consequently and additionally, none of the millennium development goals can be met without access to quantity and quality energy services, and thus the need for an energy option that is both sustainable and environmentally benign (UNDP, 2005). Biogas energy production and use could have sound benefits to both public health and climate change mitigation through cleaner combustion, and reduced consumption of biomass and wood.

Restraining methane emissions from cattle dung represents a valuable starting point for mitigating agricultural contributions to global climate change (Paustian *et al*., 2006). Anaerobic digestion can lower GHG emissions from manure significantly, as well as solve sanitation problems by improving farm hygiene. Kiambu County being richly endowed with dairy livestock has enormous quantities of cattle dung that can be transformed into a renewable energy that could go a long way in meeting household energy needs (GOK, 2005). Biogas energy has the potential to solve the most serious problem of energy supply in rural areas, where people forage for wood fuel in forests.

Importantly, quantifying the quality of gas yield potential from different feedstock is crucial since it would inform farmers on which type of feed would be most profitable; yielding energy with high calorific value, hence reducing need for alternative fuels. Assessing performance of the technology is instrumental in informing and understanding users’ post installation behavior (such as livestock feed types) to be able to determine whether regular and constant sensitization and educative campaigns to users are required. Assessing performance of the bio-digesters at the households’ level will inform policy decisions and enable effective scale-up, hence increase their economic, health and environmental benefits. Deliberate and immediate action thus need to be enforced to move the rural energy to forms that would improve the people's capacity to move out of poverty. Greater effort is needed to diversify energy technologies, improve efficiency, and take climate change into consideration in energy planning and development.

1.7 Conceptual Framework

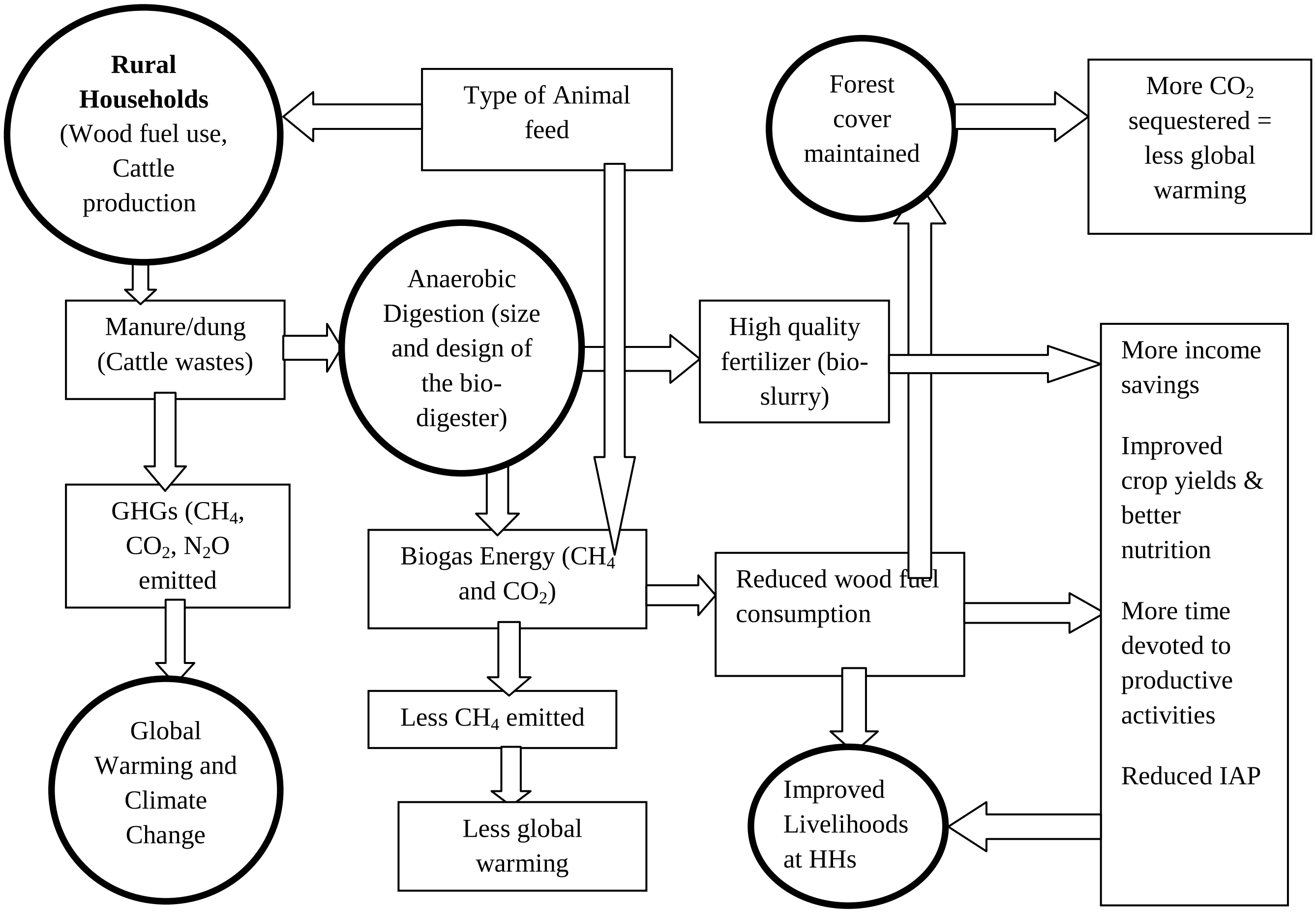

Figure 1: Conceptual framework showing the relationships between biogas energy systems, livelihoods and the environment

The study used a conceptual framework of input output (cause effect) mechanism both for the biogas production analysis (feed type and gas concentration), and on impacts of the technology on livelihoods (Figure 1).

CHAPTER TWO

LITERATURE REVIEW

2.1 Energy, Economic Development and Poverty Eradication

Energy is an important ingredient for the development process of any country (Okello *et al.,* 2013; Lee and Change, 2008). Its consumption level is an important indicator of the socio-economic development of a country, since the energy sector has strong impact on poverty reduction through income, health, education, gender and the environment linkages (Sayin *et al.,* 2005). In modern times, no country has managed to substantially reduce poverty without greatly increasing the use of energy or efficiently utilizing energy and/or energy services (Rao *et al.,* 2009). In fact, energy affects all aspects of development – social, economic and environmental (Amigun *et al.,* 2008). Therefore, energy exploitation and use is a fundamental tool in achieving economic development, since economic prosperity and quality of life are closely linked to the level of per capita energy consumption (Singh and Sooch, 2004). Provision of adequate, affordable, efficient and reliable energy services with minimum negative effect on the environment is crucial. In Kenya however, like in many developing countries, while energy demand is continuously increasing, its supply is not increasing proportionately (Chen *et al.,* 2009). Efforts to increase energy supply in a bid to match the increasing energy demand are needed. Biogas energy technology is such one option.

2.2 Overview of the Energy Sector in Kenya

Kenya’s energy sector is governed primarily by the Energy Act (2006), whose broad objective is to ensure adequate, quality, cost effective and affordable supply of energy to meet development needs, while protecting and conserving the environment (GoK, 2006). The Act addresses the importance of renewable energy and energy efficiency, but does not however expressly recognize the significance of climate change in achieving its objective. This could expose the national energy system to vulnerability to climate change. Other policies concerning the energy sector are the Least Cost Power Development Plan (LCPDP), Rural Electrification Master Plan, Sessional Paper No. 4 of 2004 (The energy policy document), The Feed-in Tariff (FiT) Policy, The Kenya National Climate Change Response Strategy, and the National economic development blueprint (Vision 2030) (GoK, 2011).

Energy provision to rural communities in the counties has proved to be a great challenge. Vast majority of these people are dependent on traditional fuels (wood charcoal, crop residues, maize stalk, cobs and dung) often using primitive and inefficient technologies (open fires). Biomass energy accounts for more than 77% of all energy consumed in the country, while petroleum and electricity account for 21 and 9 %, respectively (EIA, 2010; KIPPRA 2010; IEA, 2009). For many, this combination barely allows fulfillment of the basic needs of nutrition, warmth and light. Additionally, the current demand for wood is however outstripping the annual re-growth of wood biomass in the country. This imbalance contributes significantly to destruction of trees, and sets the stage for possible wood energy crisis, with serious social, political and environmental consequences (Ministry of Energy, 2011). The Government has prioritized efforts to shift the underlying pattern of energy consumption towards cleaner forms of energy (Ministry of Energy, 2011).

Under Kenya Vision 2030, energy is identified as a key element of Kenya’s sustained economic growth and transformation. In light of highlighted energy scarcity, there is need therefore to come up with strategies and investment plans to secure sustainable energy supply to meet the growing demand.

2.2.1: Biogas in context of Kenyas’ National Development Agenda

The overall National development objectives for Kenya include accelerated economic growth, increased productivity and enhanced agricultural and industrial growth (GOK, 2003). Kenya relies mostly on commercial energy which is not only expensive but also unsustainable thus negatively affecting the country’s’ economic growth and development. The development objectives can however only be met if energy supply is sustainable, affordable and cost-effective. In order to realize speedy economic prosperity, intensified effort to develop and use reliable, affordable and readily available energy services is needed. Biogas is such one option of an affordable energy source. Its development through accelerated uptake by households it’s of paramount importance

2.2.2: Synthesis of Biogas Technology in Kenya

The first biogas plant in Kenya was built in 1957 in a coffee farm. Its use and admiration led to about 160 plants being installed throughout the country by the year

1980. In the 1980s, the German Development Organization (GTZ) promoted the uptake of over 400 Floating drum type of digesters in the country. This was in collaboration with the Special Energy Programme, housed by the Ministry of Environment. Since then, the fixed dome design has been promoted by many development organizations including GTZ, SCODE, KENDBIP, and SNV Netherlands. The Low cost Tubular design has also been promoted particularly by the Ministries of Environment and Energy. However, biogas technology uptake has been very slow and only about 5000 units are installed in the country.

2.3 Interface between Energy and the Millennium Development Goals

While access to energy is not in the list of Millennium Development Goals (MDGs), it has been cited by the United Nations Secretary-General Ban Ki-moon, as the very foundation for all the Millennium Development Goals (United Nations, 2010). Energy plays crucial roles in addressing poverty, and meeting the MDGs. It is key to reducing hunger and improving access to safe drinking water. Energy is essential in reducing the burden of diseases and decreases child and maternal mortality. It is a key component of functioning health systems. *Energy for the Poor: Underpinning the Millennium Development Goals* (DFID, 2002), concludes that energy is essential in meeting the targets of reducing by half the number of people living in extreme poverty.

The United Nations Conference on Environment and Development (UNCED) (1992), and the World Summit for Sustainable Development (WSSD) (2002), contributed to putting energy on poverty alleviation and development agenda. Energy has been recognized as instrumental in improving third world livelihoods. In spite of this, current energy services has failed to meet the needs of the poor. Worldwide, 2.4 billion people rely on traditional biomass for cooking and 1.6 billion people do not have access to electricity (World Bank, 2013). This situation entrenches poverty, constrains delivery of social services, limits opportunities for women, and erodes environmental sustainability at the local, national and global levels (DFID, 2002).

Greater access to energy services is essential to address this situation, and support the achievement of the Milennium Development Goals (MDGs). There is a well-established link between energy services and the accomplishment of these goals (Modi *et al.* 2005; DFID, 2002b; UN-Energy, 2005). Increasing sustainable biomass production and improving cooking technology, are cited as being MDG consistent targets (UN Millennium Project, 2005).

These studies reflect an increasingly realization pronounced in DFID (2002b) that energy in developing countries needs to be understood, not primarily being about technology provision, but understanding the impacts of energy on the livelihood opportunities of the poor. Yet, it is not clear whether the documented links between energy and development are substantial, or simply hypothesized.

2.4 Energy Consumption and Climate Change Linkages

The bulk of global energy supply comes from carbon-based fuels, but whose emissions threaten the global climate, environment, human health and earth's very existence (UN-

Energy/Africa, 2011; UNEP, 2012). Energy-related greenhouse gas emissions are the main drivers of anthropogenic climate change, exacerbating patterns of global warming and environmental degradation. Three major anthropogenic GHGs are carbon dioxide, methane and nitrous oxide.

Global emissions of carbon dioxide (CO_2) have increased by more than 46 % since 1990 (UNDP, 2013). Particularly, emissions from fossil-fuel combustion are reported to have reached a record high of 31.6 gigatonnes (Gt) in 2011 (IEA, 2012b). In 2012, emissions are projected to have been 58 % above 1990 levels (Le Quéré *et al.,* 2012). Under business-as-usual conditions, global GHG emissions are predicted to increase to an annual 37 gigatonnes by 2035 (IEA, 2012c).

It is commonly assumed that biomass fuels are renewable in nature and greenhouse-gases neutral, because the carbon released during combustion in the form of CO_2 is soon taken up by re-growing vegetation (Smith *et al.*, 2000a). However, burning of wood fuel could result in net emission of $CO_{2,}$ by decreasing the forest area and standing stock of carbon in forests (Subedi *et al.*, 2012). Wood fuel contributes to GHG emissions through unsustainable harvests and incomplete combustion of biomass. When one tonne of dry wood burns or decays, 1833 kg of CO_2 is emitted (Lamlom and Savidge, 2003). It is further estimated that traditional charcoal production emits nine tons of CO_2 for every ton of charcoal produced (SEI, 2008). In the pyrolysis process, carbon is emitted to the atmosphere in the form of CO_2, CO and CH_4. Emission of black carbon from biomass combustion may also exacerbate the effects of climate change (Venkataraman *et al.* 2005).

Over the last three decades, carbon dioxide and other greenhouse gases have loaded up in the atmosphere (average increment of 1.6% per year), heating the planet and pushing humanity onto a climatic swing of weather irregularities. High-temperature records in many places are already being witnessed with increased frequency, and hotter temperatures are expected. The world has warmed by 0.8°C since the Industrial Revolution, with most of the rise in temperature coming since the 1970s.

Kenya currently has no laws or policies that deal explicitly with climate change. The one policy that has attempted to address climate change to some extent is the draft National Environmental Policy of 2008. Kenya’s Environmental Management and Coordination Act 1999 have only a few provisions relevant to the mitigation of climate change. Kenya’s National Climate Change Response Strategy (NCCRS) seeks to respond to the challenges climate change is posing to Kenya’s socioeconomic development (GOK, 2013).The Strategy recommends that a comprehensive climate change policy and related legislation be put in place (GOK, 2013).

In the absence of policy actions, emission are expected to continue and this will veer temperatures and weather patterns that civilization is adapted to, to even further away from norm. Promotion of renewable energy can decisively limit carbon emissions from energy use, bearing the potential to save an equivalent of 220–560 gigatonnes of CO_2 between 2010 and 2050 (IPCC 2011).

2.4.1 Total GHG Emission per Unit of Useful Energy for Cooking – Emission Factors

Greenhouse Gases (GHGs) can be measured by recording emissions at source by continuous emissions monitoring or by estimating the amount emitted - by multiplying activity data (such as the amount of fuel used) by relevant emissions conversion factors. In cooking systems, emission factors form the basis of estimating emissions. These conversion factors allow activity data (for example, litres of fuel used) to be converted into kilograms of carbon dioxide equivalent (CO_2eq). CO_2eq is a universal unit of measurement that allows the global warming potential of different GHGs to be compared (DEFRA, 2012).

Total quantity of fuel used in a cooking system multiplied by corresponding emission factors gives an estimation of the total quantities of various GHGs emitted from the system. These factors heavily depend on various parameters involved in the combustion process such as type of fuel, type and design of burner, operating conditions, among others. The total CO_2 equivalent concentration of all long-lived GHGs was in year 2007 estimated to be about 455 ppm CO_2eq, although the effect of aerosols and land-use change reduces the net effect to levels ranging from 311 to 435 ppm CO_2eq (Climate Change, 2007).

Lamlom and Savidge (2003) have illustrated that when one metric tonne of dry wood burns or decays, 1833 Kg of CO_2 is emitted. Dry wood contains about 50% carbon but the carbon content of growing trees is much lower since they contain much higher proportion of water than dry wood (Gustafson *et al.*, 2009).

2.5 Methane Emissions from Cattle Manure

The Intergovernmental Panel on Climate Change (IPCC) estimates that globally, agriculture contributes 10% of anthropogenic CO_2, 40% CH_4 and 60% N_2O (USDA, 2004). Methane is the second most important GHG with global warming potential (GWP) 25 times that of CO2 (EPA, 2010). EPA estimates that the atmospheric concentration of CH_4 is increasing at 1% per annum, and has more than doubled over the past centuries. Methane affects climate directly by its interaction with long-wave infrared energy, and indirectly through atmospheric oxidation reactions that produce carbon dioxide. The more than 500 million metric tonnes of CH_4 entering the atmosphere annually, exceeds its atmospheric and terrestrial oxidation, and this is expected to cause about 15% global warming in the next 50 years (EPA, 2010). CH_4 is highly efficient than CO_2 in absorbing infrared energy (Harvey *et al.,* 2010), and hence, despite its relative low concentration, its contribution to global warming is enormous. In large quantities, methane destroys the ozone that protects the earth against harmful ultraviolet radiation from the sun.

About 7% of CH_4 emissions result from animal excrement approximated at 20-30 million tonnes of CH_4 per year. Cattle manure management can result in CH_4 emissions depending on the system in place. For instance, dry lot systems usually has relatively high nitrous oxide and low methane emissions, while anaerobic lagoons have low nitrous oxide and varied methane emissions (USDA, 2004). In the United States, manure accounts for 7 % of total anthropogenic CH_4 emissions and 4 percent of N_2O

emissions (EPA, 2008). Emissions from animal manure must therefore be taken into account when GHGs mitigation potential strategies are evaluated.

2.6 Biogas Energy and Climate Change Mitigation

An increase in concentration of CO_2 and other GHGs in the stratosphere leads to global warming, and ultimately, climate change. This has severe adverse effects on human health, ecological productivity, biodiversity, water reserves, and on socio-economic groups whose adaptive capacity is low, especially the poor in developing countries (IPCC, 2001). Climate change can exacerbate poverty and undermine sustainable development.

From an economic perspective, the *Stern Review* (Stern, 2006) found that in order to minimize the most harmful consequences of climate change, concentrations of GHGs would need to be stabilized below 550 ppm CO_2eq. The Review further argues that any delay in reducing emissions would be costly and dangerous (IPCC, 2007). Thus an endeavor of controlling GHGs emissions to the atmosphere is needed. Global mitigation efforts can enhance sustainable development prospects by reducing the risk of adverse impacts of climate change. Mitigation can also provide co-benefits, such as improved health outcomes and better livelihoods. Mainstreaming climate change mitigation is thus an integral part of sustainable development.

In Kenya, like in economies everywhere, the energy sector has a key role in mitigation of climate change. Biogas energy technology has important duo climatic effect, and therefore a mitigatory mechanism to global warming and climate change. In addition to converting methane into fuel, use of biogas reduces CO_2 emissions through reduced demand for fossil fuel and firewood. A study in Nepal showed that a biogas plant measuring $6m^3$ can save more than four tones of firewood and 32 litres of kerosene (Winrock and Eco Securities, 2004). Using manure for biogas production has twin benefits; one, it represents a valuable starting point for mitigating methane contributions to global climate change, and two, it is an affordable and locally available raw material for bio energy production.

Renewable energy has the potential to enhance energy security, mitigate climate change, create employment and enable developing countries make substantial foreign exchange savings (Winkler, 2005; UNEP, 2012; Weiss, 2011; GoK, 2012a).

2.7 Understanding Biogas Energy

Biogas technology is a renewable form of energy that utilizes various organic wastes in the absence of oxygen to produce combustible mixture of methane and carbon dioxide gases, mineralized water and organic fertilizer (bio-slurry) (Gautam *et al*., 2009. In other words, the technology recovers biogas by harnessing anaerobic degradation pathways controlled by micro-organisms. The gas is principally a mixture of methane (CH_4) and carbon dioxide (CO_2), and other trace gases such as hydrogen sulphide (H_2S) (Singh and Sooch, 2004; Shin *et al.*, 2005). Methane makes up the combustible part of biogas. It is a colorless, odourless and highly inflammable gas, second only to hydrogen in the energy released per gramme of fuel burnt; hence it’s potential as a household energy source. It has a boiling point of -162°C and burns with a smokeless blue flame and is non-toxic. Methane is also the main constituent (77-90%) of natural gas.

Chemically, methane belongs to the alkanes (saturated hydrocarbons) and is the simplest possible form of these. At normal temperature and pressure, methane has a density of approximately 0.75 kg/m^3. Pure methane has an upper calorific value of 39.8 MJ/m^3, which corresponds to 11.06 kWh/m^3 (Batzias, 2004).

Small-scale domestic biogas is one of decentralized renewable energy technologies (RETs) advocated for rural people. A biogas digester consists of one or more airtight reservoirs into which a suitable feedstock (cow dung, human waste, or any other organic waste) is placed, either in batches or by continuous feed. Small-scale digesters for household use are commonly made of concrete, bricks, metal, or plastic. Larger commercial biogas digesters are made mainly of bricks, mortar, and steel. The end product is the gas, which can be connected to a household stove for cooking, to a light fixture with a gauze mantle for lighting, or to other appliances with simple natural gas plumbing. The gas burns like liquefied petroleum gas.

Various designs of biogas plants and sizes exist throughout the world (Tom and Michael, 2011). The *Fixed dome* design originated with the Chinese. The main part of the plant is a brick and cement digester in which the organic inputs are collected and anaerobically converted into a combustible gas. Connected to the digester, there is an inlet tank in which the inputs get mixed with water prior to feeding into the digester; and a compensation tank where the by-product (bio-slurry), gradually accumulates until it overflows to a composting pit. The *floating drum* type plants, (Indian design) have an underground well-shaped digester with inlet and outlet connections through pipes at its bottom on either side of a partition wall (Rijal, 1985). An inverted drum (gas holder), is placed in the digester, and rests on the wedge shaped support and guide frame at the level of a partition wall. This drum can move up and down along a guide pipe with the accumulation and disposal of gas, respectively. The weight of the drum applies pressure on the gas to make it flow through the pipeline to the point of use (Singh and Sooch, 2004). The *Tubular* or the low-cost polythene digester is adapted from the Taiwanese model. In such, the substrate flows through a tubular polyethylene or PVC bag (the reactor) from the inlet to the outlet. The gas is collected by means of a gas pipe connected to a reservoir. Most household digesters range between 4 to 16 m^3 in size, with a few institutional and community ones, with a capacity of 36 and 54 m^3 (Singh and Sooch, 2004).

2.7.1 The Process – Biogas Formation (Methanogenesis)

Biogas is produced by methanogenic bacteria while acting upon biodegradable material under anaerobic conditions. Complete decomposition of organic matter to CH_4 and CO_2 under oxygen-depleted conditions is complicated and is an interaction between different bacteria. The process takes place in three stages: hydrolysis, acidogenesis and methanogenesis. During hydrolysis (first step) long-chain molecules, such as protein, carbohydrate and fat polymers are broken down to monomers (small molecules). Different specialized bacteria produce a number of specific enzymes that catalyze the decomposition. During the second stage (fermentation/acidogenesis), acid-producing bacteria convert the simplified compounds into acetic acid (CH_3CO_2H), hydrogen (H_2), and carbon dioxide (CO_2). Approximately 50% of the monomers (glucose, xylose, amino acids) and long-chain fatty acids (LCFA) are broken down to CH_3CO_2H. 20% is converted to CO_2 and H_2, while the remaining 30% is broken down into short-chain volatile fatty acids (VFA). In this process, the facultative anaerobic bacteria utilize oxygen and carbon, thereby creating anaerobic conditions necessary for methanogenesis.

The third and last step (methanogenesis) is undertaken by the methanogenic bacteria or methanogens. In this stage, the obligatory anaerobes decompose compounds with low molecular weight, (CH_3COOH, H_2, CO_2), to form CH_4 and CO_2 (Gate, 1999). Two different groups of bacteria are responsible. One group degrades acetic acid to methane and the other produces methane from carbon dioxide and hydrogen. Under stable conditions, around 70% of methane production comes from the degradation of acetic acid, while the remaining 30% comes from carbon dioxide and hydrogen (Gate, 1999).

The bacteria involved in the fermentation process are sensitive to a range of variables that ultimately determine gas production. Temperature is the most critical consideration. Most digesters operate in the mesophylic range (35-40°C), but others are designated to operate in the thermophylic range of 50-60°C, and a few at psychrophylic range (15-25°C) (Paustian *et al.,* 2006). Loading rate and retention period of material are also important. Other factors likely to affect methanogenesis are pH and nutrient content of the slurry (Forster-Carneiro *et al*., 2008). The resulting biogas consists of CH_4 and CO_2, and traces of H_2S. Its exact composition vary according to the substrate used in the methanogenesis process, but as an approximate guide, when cattle dung is the main substrate for fermentation, the resulting gas will be between 55-66% CH_4, 40-45% CO_2, plus a negligible amount of H_2S and H_2 (KVIC, 1993).

2.8 Biogas Production and Cattle Feed Type

Different feedstock's have different gas yield potential. Materials with high C:N ratios, such as waste wheat, typically have a much lower gas yield than materials with a low C:N ratio, such as cattle and pig manure. Typical values for methane content range from 50-60 % for animal manure and up to 75% for feedstock containing fats (Marchaim, 1992). The composition of specific biomass, the ratio between carbohydrates, proteins and fats has an effect on how much methane the biomass contains, and therefore on its calorific value (Stephen and Yebo, 2012).

Cattle diet can play an important role in methane production. According to MacDonald and McBride (2010), the ultimate yield of biogas depends on the composition and biodegradability of the organic feedstock. However, it is difficult and expensive to measure the composition directly due to biological instability of the material, their potentially pathogenic nature and the potential for rapid autoxidation (Russ *et al*., 2004).

Biogas production potential from different feed substrates varies as does process operation conditions and process stability (Jungbluth *et al*., 2001). The ratio of methane to carbon dioxide depends on the composition of the waste. In their study, Holter and Young (1992) found out that methane emissions was influenced by the cows' physiology and feed composition, in addition to temperature, presence of toxic materials, pH and alkalinity, the hydraulic retention time (HRT), the solids retention time (SRT), food to micro-organisms ratio (F/M), rate of digester loading and the rate at which toxic end products of digestion are removed (Burke, 2001). However, only a few studies have reported on the quality of methane production based on cattle feed type either as single feed or combination of feeds. Co-feeding can increase gas quality and the energy output. Research is needed to identify the effect of cattle feed type on gas yield.

2.9 Digester Size and Emissions Reduction

Agricultural bio-digesters reduce GHG emissions and generate clean energy (Clean Development Mechanism). Emissions reduction depends on many factors, including digester design and size. Studies by Winrock (2004), in Nepal, found that a biogas plant measuring $6m^3$ was able to mitigate 5 tonnes of CO_2-equivalent per year (Biogas Support Programme, 2000). According to Shrestha *et al*. (2003), biogas plants of sizes 4, 6 and 8 m^3 mitigated about 3, 4 and 5 tonnes respectively of CO_2 per year. Further, a study by Winrock and Eco-Securities (2004) shows carbon reduction per digester at 4.6 tonnes of carbon dioxide equivalent. Similarly, AEPC (2008), found GHGs reduction rate of 4.99 tonnes. Similar research findings are lacking in Kenya.

2.10 Benefits of Biogas

Renewable energy technologies (RETs) provide multiple benefits that can contribute to addressing vital local and global development challenges (World Bank, 2008). Small-scale biogas digesters in particular have great potential to contribute to sustainable development by providing a wide variety of socioeconomic benefits (Mshandete and Parawira, 2009), including diversification of energy supply, creation of domestic industries and employment opportunities (Rio and Burguillo, 2008), increased crop productivity and provision of clean fuel (Arthur *et al.*, 2011; Mwakaje 2008; Katuwal and Bohara, 2009). The knock-on benefits may include improved subsistence, increased food security, and (or) income generation. Biogas can have significant health benefits by alleviating poor indoor air quality.

Use of biogas system in livestock rearing community can reduce methane emissions (Alvarez and Liden, 2008) and enhance soil fertility. The slurry that is returned after methanogenesis is said to be superior in terms of its nutrient content. Arthur *et al.* *(*2011) presented an analysis of biogas benefits in Ghana, where he showed that the benefits could be significant if uptake of the technology is accelerated. Yu *et al.* (2008) estimated the environmental benefits of bio-digesters in China by determining GHGs reduction. Their study revealed a reduction of 45.59 $x10^6$ tonnes of CO_2 equivalent per annum between 1991 and 2005 in rural China. Up to date however, only few studies have been done to assess and ascertain the said benefits. Moreover, most of these studies have been done in the Asian countries and context, where the social economic conditions are different from those in Kenya and East Africa at large. A systematic study to bring together and ascertain the benefits of biogas digesters in Kenyan context is needed. This forms the basis for the current study.

2.11 Biogas Use in Developing Countries

Biogas technology has been known for a long time, but in recent years, interest has especially increased, especially due to the high costs and the rapid depletion of fossil fuels as well as their environmental shortcomings. Worldwide, about 16 million households use small-scale biogas digesters (Renewables, 2005). In developing countries, small-scale anaerobic digesters are used to meet the heating and cooking needs of individual rural communities. The technology is being used successfully in Asia, but also in Latin America and some regions of West Africa. In China and India, biogas technology is particularly highly disseminated in smallholder farming, and has become part of the standard practice in households. China has an estimated 8 million anaerobic digesters while Nepal has 50,000 (IEA Bioenergy, 2005), and there are thousands of polyethylene digesters operating in Vietnam.

The development of large-scale anaerobic digestion or biogas technology in Eastern Africa is still at an embryonic stage but the potential is promising. Ghana, Nigeria, Uganda, Rwanda and Kenya are a few pioneer African countries (Amigun *et al.,* 2008).

2.12 Biogas Energy Adoption and Use at Household Level

Use of improved energy technologies in Kenya has often been unsuccessful. Most households do not adopt the technologies at all, and if they do, use them in ways that do not achieve the sought after level of reductions in wood fuel use and harmful emissions (Barnes *et al*., 1994). It can be argued that the challenge of ensuring successful uptake and proper use of improved energy technologies -such as biogas, in rural households stems from the twin failure of adoption and implementation. Adoption in this context refers to the decision to acquire the new technology, while implementation refers to the households' actual use of the new technology (Klein and Knight, 2005). These failures in turn stems from a misunderstanding of households' decision making processes (around improved technology adoption), which are grounded in the livelihoods of the people, the social, political, cultural, economic and ecological dimensions of energy security, as well as access to alternative sources of energy to meet energy supply and demand (Barnes *et al.,* 1994). Biogas technology uptake and use in rural Kenya could be limited by some or all of these factors. It is in the interest of this study to investigate these factors.

2.12.1 Innovation Diffusion Theory and Biogas Technology

Diffusion research focuses on conditions which increase or decrease the likelihood that a new idea, product, or practice will be adopted by members of a given culture. Studying how innovation occurs, (Rogers, 1995) argued that it consists of four stages: invention, diffusion (or communication), time and consequences. The nature of communication networks and the role opinion leaders, determine the likelihood that innovation will be adopted. Opinion leaders exert influence on audience behavior via their personal contacts, but additional intermediaries (change agents and gatekeepers) are also included in the process of diffusion (Rodgers, 1995).

According to Rogers (1995), in a given technology, there are five categories of adopters, who are: (i) innovators, (ii) early adopters, (iii) early majority, (iv) late majority, and (v) laggards. These categories follow a standard deviation curve. Very few (2.5%) (innovators) adopt the innovation in the beginning. Early adopters make 13.5% a short time later, followed by the early majority (34%), and the late majority (34%). Ultimately, the laggards make up 16% (Rodgers, 1995). Lunds (2006) describes the process as beginning with research and development, followed by demonstration and pilot production, which leads to early market introduction and ultimately to market diffusion.

Diffusion of environmentally sound technologies such as biogas is essential to realize sustainable development goals. However, the diffusion rates are context specific and depend largely on specific social, economic and technological factors. These factors that either hinder or facilitate, and drive the process are often interlinked, making diffusion a complex phenomenon. Renewable energy technologies (RETs) for instance are mainly driven by impending environmental and energy security considerations arising from use of fossil and wood fuels.

2.13 Biogas and Rural Livelihoods

Biogas technology is considered by many experts to be an excellent tool for improving life, livelihoods and health in the developing world (Renewables, 2005). Energy is an important ingredient for the development process of any country, and its consumption levels, a good indicator of socio-economic development level. The energy sector has strong impact on poverty reduction through income, health, education, gender and the environment linkages (Sayin *et al*., 2005). In modern times, no country has managed to substantially reduce poverty without greatly increasing the use of energy or efficiently utilizing energy and/or energy services (Rao *et al.*, 2009). In fact, energy affects all aspects of development – social, economic and environmental (Amigun *et al.*, 2008).

There is a large body of literature on energy and sustainable livelihoods (Uphoff, 2006; Peril *et al.*, 2006; Almas *et al.*, 2003; Dalal-clayton 2003; Hussein 2002; Babington 2000; Carney *et al*., 2000; DFID, 1999; Scones, 1998), but very little research demonstrating the impact of biogas on livelihoods has been carried out. Chambers and

Conway (1992), pointed out that a livelihood comprises the capabilities, assets and activities required for a means of living.

2.13.1 Sustainable Livelihood Approach (SLA) and Energy

When we look at poverty as a multidimensional phenomenon, in the light of human development, energy can be seen as one important factor which affects in various ways people's capabilities to live better lives. To capture these ways in their complexity, sustainable livelihood approach (SLA) can be a valuable tool (Muleguetta *et al.,* 2006). People, who are in the centre of the framework, are seen as operating in the context of vulnerability. They have access to certain assets (natural, human, financial, physical and social) that gain their meaning and value through the existing social, institutional and organizational environments. This influences the livelihood strategies (ways of combining and using the assets) available to people in pursuit of livelihood outcomes that meet their own livelihood objectives (DFID, 1999).

A livelihood is sustainable when it (i) can cope with and recover from stress and shocks; (ii) can maintain or enhance its capabilities and assets; (iii) can provide sustainable livelihood opportunities for the next generation; and (iv) contributes net benefits to other livelihoods at the local and global levels, in both the long and the short term (DFID, 1999). Clean and affordable energy is, according to the DFID's guidelines for SLA, one of the infrastructures essential for sustainable livelihoods. Linkages between SLA components and energy can be modeled conceptually (Figure 2). The theoretical model assumes that each person/household in a community is able to achieve a livelihood.

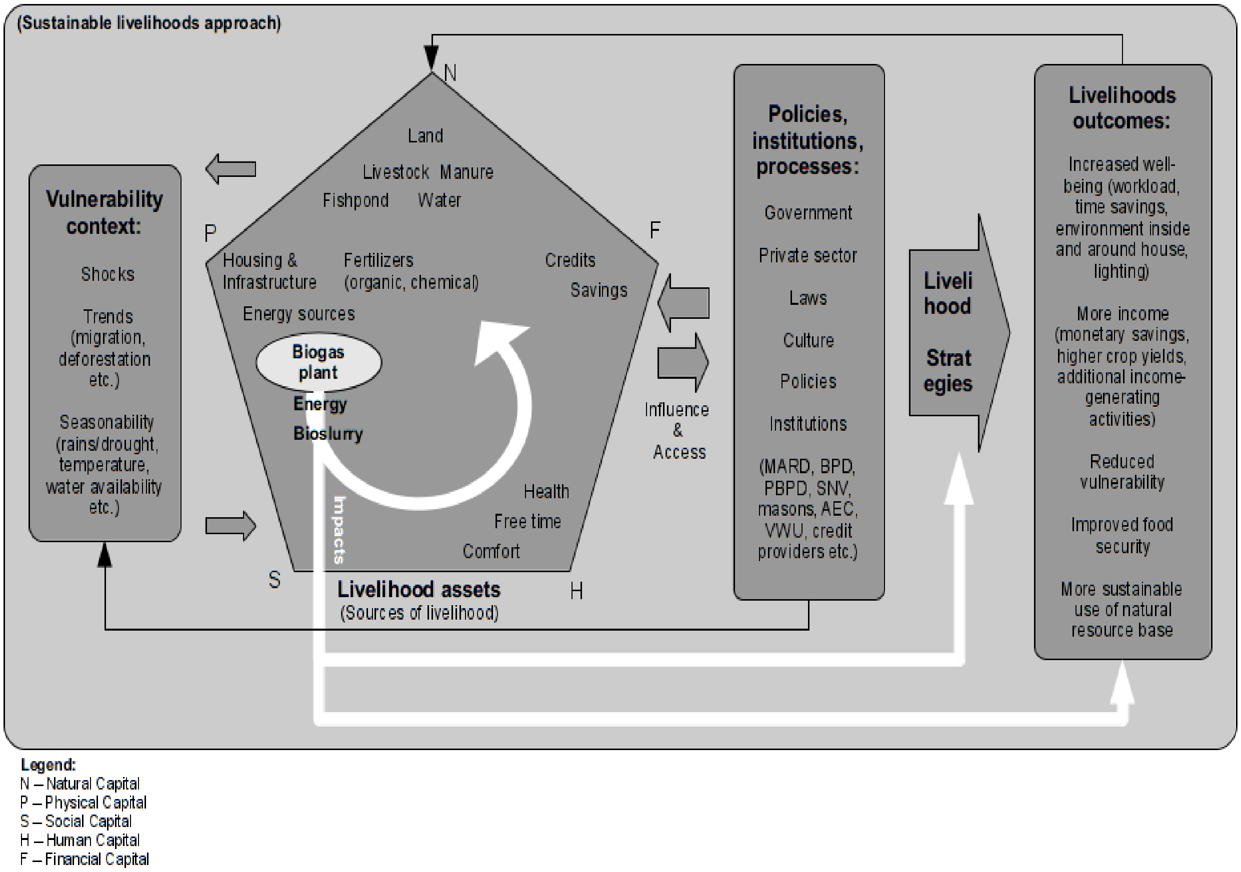

Figure 2: Sustainable Livelihoods Approach Model (DFID, 1999)

2.14 Knowledge Gap

While biogas energy has huge potential, monitoring its performance has remained a significant setback in policy decisions. Currently, advocacy is hugely based on outdated data and anecdotal evidence. There is little or no laboratory based information on biogas technology in rural Kenya. Rigorous analytical studies on the technical performance and on livelihood impacts on the wide range of bio-digesters designed and deployed in the field are rare. While studies have been carried out to ascertain biogas production using organic wastes in countries like India and Nepal, only minimal studies on biogas production and use at the household level in Kenya have been done. No analytical studies have been done to quantify the quality of gas produced under different feeds that farmers in the area are using on their livestock.

Since adopters of the technology in the study area solely use livestock dung as the main substrate for the anaerobic digestion, it is important to study how the gas produced is affected by the type of cattle feed. In addition, different designs and sizes of digesters exist among the few households that have installed the technology. Literature indicates that no study have been conducted in the area to determine the quality of biogas produced under the different bio-digesters. Furthermore, most current data in literature concerning methane gas yield come from template countries (Shell Foundation, 2007). There appears to be no comparable information in the tropics.

Additionally, no substantive data are available on carbon emission reduction resulting, when wood fuel is substituted with biogas fuel in rural households. Quantifying the amount of wood fuel savings in households is key to informing the levels of GHGs emission reduction arising from biogas production and use. There is need therefore for substantial advancement in the understanding of biogas energy transition and innovation adoption and implementation to inform the policy and practice models that drive government and non-governmental organizations approaches to adoption and implementation of alternative energy technologies (Hiemstra-van der Horst and Hovanka, 2008).

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was carried out in five different Sub-counties in Kiambu County; Githunguri, Kiambu, Lari, Limuru and Kikuyu (Figure 3). Kiambu County was purposely chosen since it formed part of implementation area for funded projects by Dutch and German Governments, in Kenya, on promoting uptake of biogas energy technology. These sites offered a unique opportunity to study biogas energy adoption decisions, and its potential for improving livelihoods, and in mitigating climate change. Kiambu was also targeted because it is among the few Counties in Kenya with high concentration of households practicing zero-grazing dairy farming, a favorable factor in biogas production

3.2 Physical Description of the Study Area

Kiambu County is one of the 47 Counties in Kenya. It is located in Central Kenya, and borders Murang'a County to the North and North East, Machakos County to the East, Nairobi and Kajiado Counties to the South, Nakuru County to the west and Nyandarua County to the North West. The capital of the county is Kiambu town. The County is predominantly rural, but rapidly becoming urban, due to influence of Nairobi. It comprises 2,543.4 sq km of the Central Highlands, and it is the fourth most densely populated county in the country, having an estimated human population of 1,623,282 (KNBS, 2010). Average farm and household size is 1.1 ha and 4.8 people respectively.

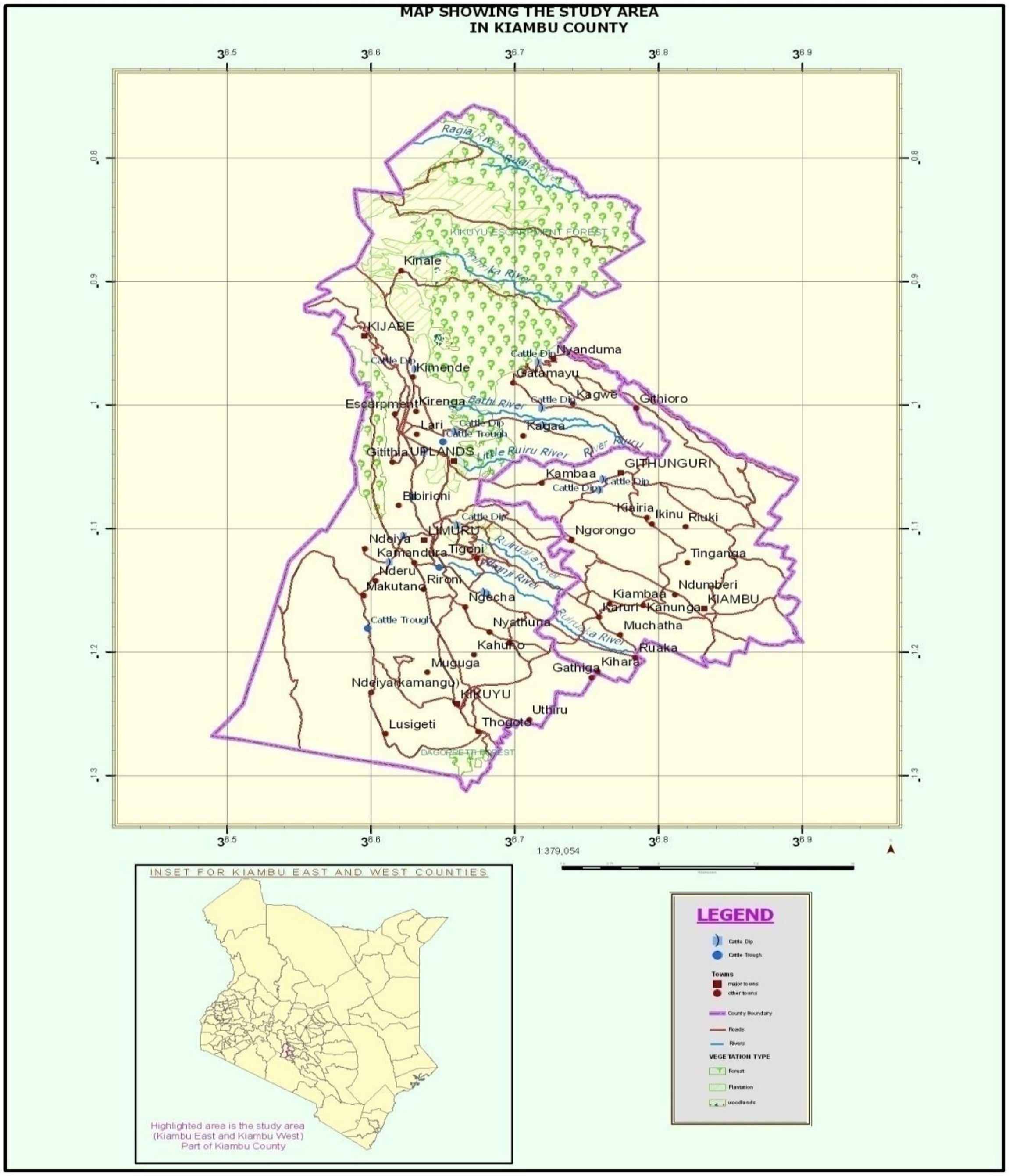


Figure 3: Map of Kiambu County showing the Study Area

Altitude ranges from 1,400 m in the southeast to 2,400 m in the north, with annual mean temperatures of 13.4 to 21.9°C. Most of the area have Humic Nitisols (red kikuyu soils), and are intensively cultivated. A combination of good soils, suitable climate, well-developed infrastructure, and proximity to the country's main market and capital; Nairobi, makes Kiambu County the most-economically viable farming region in the country. Vegetable cultivation and dairy production are the most common farming activities because of the small farm sizes, and the high demand for produce in the city. Coffee, tea, pyrethrum, maize, beans and bananas are also grown. Dairy cattle of exotic breeds or their crosses with indigenous breeds are reared, and integrated with cropping activities. The cattle are permanently housed and hand-fed on fodder crops, crop residues, grass and other material collected off-farm, and commercial feeds (zero-grazing).

3.3 Data Collection

Both primary and secondary data were instrumental in informing this study. Primary data was collected through observation, structured personal interviews with household heads and key informants, and focus group discussions. Participatory experimental research on biogas was also carried out. Secondary data was collected through desktop research and review of relevant literature from internet and publications. Data collected included mainly socio-economic and demographic characteristics of households (age and educational status of household head, experience of household in biogas production and use, household size, farm size, farm assets), household perceptions of biogas technology, and detailed financial biogas plants installation and operational costs and benefits.

3.4 Household Selection and Sampling Procedure

Selection of respondent households was done through purposive stratified sampling protocol. Representative biogas technology adopters and non-adopters were sampled from the five Sub-Counties This was done using a participatory scoring matrix, and guided by area resource persons. In order to capture as much local variation and reduce as much error as possible, the sample in each zone was spread across the entire area.

In total, 200 households that had adopted the technology were sampled, 40 from each Sub-County. Given the limited number of biogas users, purposive sampling was employed, and most households in the sampling frame who were known to be having a biogas plant were actively selected, irrespective of the type or size of the digester owned. As it would come out in the analysis, the 40 households from each Sub-county, comprised of three digester types; the Fixed dome, Floating drum and the Tubular of varied sizes. Additionally, About 125 non-user households (25 households from each of the five zones) were randomly selected from the same study population and studies conducted on them, similar to those conducted on the adopters. These formed a control group, and enabled a comparative study.

3.5 Determination of Impacts of Biogas Technology on Livelihoods

In addition to in-depth household surveys, Action Learning Case Studies (ALCS) of households that had successfully installed and using biogas technology were used. Two households that had successfully adopted the technology were included in the case studies analysis. Oral interviews with households’ heads were conducted using prior defined questionnaires (Appendix 1). In order to capture a wide range of possible impacts, the Sustainable Livelihood Framework (SLF) model was used. The model draws on the Sustainable Livelihood Approach (SLA) designed for the UK Department for International Development (DFID) (1999), as a framework for assessing community assets. A conceptual framework adapted from the original Sustainable Livelihood Framework (Scoones, 1998) to include complex systems thinking (Holling *et al.*, 1995; Kay *et al.,* 1999) was used to analyse selected case studies of biogas households. Two main considerations for assessing impacts on livelihoods were the potential for livelihood diversity and intensity. Specifically, benefits accruing from use of biogas to the household were studied. Among these included; financial, health, time, food security, family welfare and environmental among others.

3.6 Determination of Fuels and Wood fuel Savings

In-depth structural interviews were carried out with respondents to determine fuel demand, fuel expenses and usage patterns. Adopter households were asked to quantify the amount of firewood and charcoal they used on weekly basis before, and after they installed the biogas plant (pre and post biogas installation). Likewise, non-adopter households were required to quantify the amount of firewood they consumed in a week. Firewood consumption was recorded on the basis of mass of backloads, cartloads and bundles, collection time and number of loads collected. The difference in fuel consumption between adopters and non-adopters, and also the difference pre and post installation for the adopter households, gave an indication of the amount of wood fuel avoided as a result of use of biogas energy. Consumption of other fuel types including liquefy petroleum gas, electricity, and kerosene pre and post installation phases were quantified too. Electricity use was measured by proxy using monthly payments, since most respondents could not recall the actual number of units consumed, and paper bills were also not available.

3.6.1 Determination of Firewood and Charcoal Weight

The weight of one load of dry firewood was estimated by determining the weight of ten backloads and ten cartloads, sampled randomly in the area. Wood pieces were tied into bundles with a cord and weighed. A hanging scale with 0.01 kg accuracy was used. A backload was found to weigh approximately 25Kgs by dry weight, while a cartload weighed 250Kgs. Charcoal was weighed in gunny bags. An empty bag was weighed and the weight recorded. The bag was then weighed with the charcoal and this weight recorded as well. The difference in the two weights gave the weight of the charcoal.

3.6.2 Determination of Forest Area Saved

By extrapolation, the total amount of wood saved gave an indication of the extent of forest cover conserved.

3.7 Determination of Net Emission Reductions of CH_4 and CO_2 Gases

Emission reductions are assumed to result from transforming methane (from dung decomposition) into usable fuel, and eliminating or minimizing carbon dioxide from wood and fossil fuels combustion. Wood fuel contributes to green house gases (GHGs) emissions through unsustainable harvests and combustion of biomass. These GHGs can be measured by recording emissions at source by continuous emissions monitoring or by estimating the amount emitted, by multiplying activity data (such as the amount of fuel used) by relevant emissions conversion factors. These conversion factors allow activity data (for example, litres of fuel used) to be converted into kilograms of carbon dioxide equivalent (CO_2eq); a universal unit of measurement. In this study, annual carbon emission reduction was calculated from fuel consumption reductions Mendis and Van Nes (1999), gives emission co-efficient for wood fuel and kerosene as 1.5tons CO_2eq per ton of firewood and 2.5 tons CO_2eq per 1000 litres of kerosene.

3.8 Gas Production

Participatory experimental research methods were used, where participating adopter households' digesters and practice were used. Raw cattle dung (amount was based on the digester size) was collected from the cattle pen and poured into a 100 L tank and equal amount of clean water (1:1) added. The mixture of raw manure and water (substrate) was then homogenized by mixing thoroughly with a wooden stick, and fed into farmers installed bio-digester through the inlet. The mixture was then left to undergo anaerobic digestion for three days under airtight conditions. Retention time was taken at 3 days since the digesters were already in use, and therefore had the inoculum necessary for gas production. Gas sampling was done every three days and concentration of constituent gases determined. Raw substrate was added every three days and the counterpart slurry displaced from the digester through the outlet.

3.9 Gas sampling and Analysis

The gas generated was collected by displacement method since the gas is lighter than counterpart slurry. The gas was then tapped using gas pipes and channeled into the cooking devices. Gas sampling was done at the point where the gas pipe connected to the burner. (It was not possible to sample the gas right in the digester or at the valve immediately outside the digester. First because the digesters were concrete or metal made, and therefore not penetrable, and second because the pipes were permanently fixed and owners did not allow disconnection for fear of gas leakage). Sampling and analysis of gas was done by use of Portable Biogas Analyzer (Biogas 5000) from Geotech Instruments, UK, Ltd. Variables measured included; percent CH_4, CO_2, O_2, and H_2S. Gas flow rate, pressure and temperature were also determined, though these were challenging to ascertain, since they could have been influenced by the pipes intricacies and the atmospheric temperatures. Biogas 5000 gas analyzer enables consistent collection of data, its ATEX and IECEx certified, has CH_4 and CO_2 accuracy of ±0.5% after calibration. It measures H_2S in a range of 0-500ppm. Methane and carbon dioxide gases were measured using duo beam infrared absorption, while oxygen was measured by a galvanic cell sensor. Biogas 5000 analyzer have been used to measure gas composition with repeatable accuracy on farm waste projects, food processing plants and waste water treatment facilities, meeting Clean Development Mechanism (CDM) requirements. Calibration of the analyzers was done every 5th day using certified calibration gas, comprised of 60% CH_4 and 40% CO_2 mixture. This was done to maintain the integrity of the process.

Biogas samples were collected from 25 farms. The gas was analyzed for CH_4, CO_2, O_2, H_2S, pH, temperature, pressure and flow. Throughout the analysis, triplicate and sometimes quadruple samples were collected. Water moisture was trapped and removed using water trap inline filters, and these were replaced weekly upon saturation. To check for any variation in the concentration of the gas, measurements were taken weekly for four weeks.

3.10 Determination of the Effect of Digester Size and Design on Gas Quality

Three digester types; Fixed dome, Floating drum and Tubular were investigated. Different sizes of the three types were investigated too and included; 4, 8, 10, 12, 16, 24, and $32m^3$. Effects of the digester type and size on gas quality was determined. The floating drum type plants, which are Indian designed, have an underground well shaped digester with inlet and outlet connections through pipes at its bottom on either side of a partition wall (Rijal, 1985). An inverted drum (gas holder), is placed in the digester, and rests on the wedge shaped support and guide frame at the level of a partition wall. This drum can move up and down along a guide pipe with the accumulation and disposal of gas, respectively. The weight of the drum applies pressure on the gas to make it flow through the pipeline to the point of use (Singh and Sooch, 2004). The fixed dome model is Chinese designed (Kandpal *et al.*, 1991). In this type, the digester and the gas holder are integrated parts of the brick masonry structure and the digester is made of a shallow well having a dome shaped roof on it. The inlet and outlet chambers are connected with the digester through large chutes. These chambers are above the level of the junction of the dome and the cylindrical well. The gas pipe is fitted on the crown of the masonry dome. The tubular type is a plug flow reactor, with the substrate flowing through a tubular polythene bag from the inlet to the outlet, while biogas is collected via a gas pipe. The gag is laid in a trench and covered in order to increase the process temperatures and minimize on fluctuations.

3.11 Determination of Cattle feed type on Gas Composition

Cows were fed on nine different feeds, which were a combination of available feeds (farmers' practice). These included; i)Napier grass + Dairy meal, ii)Napier grass + Maize Stover, iii)Napier grass + Maize Stover + Dairy meal, iv)Napier grass + Maize Stover + Dairy meal + Chicken dropping, v)Napier grass + Maize Stover + Dairy meal + Fodder legumes, vi)Napier grass + Silage + Dairy meal + Molasses, vii)Napier grass + Maize Stover + Sorghum/barley waste, viii)Napier grass + Maize Stover + Dairy meal + Brewers grains, ix)Napier grass + Maize Stover + Dairy meal + Pig feed. The effect of cow feed on biogas quality was investigated by comparing CH_4 and CO_2 content in different biogas samples from the various feed composition.

3.12 Data Presentation and Analysis

Survey data gathered was entered into field books and questionnaire matrices, later entered into Statistical Program for Social Scientists from SPSS Inc, while experimental data was entered into Excel spreadsheets and exported to SAS statistical software. After thoroughly cleaning the data and checking for any erroneous entries, detailed statistical analysis were carried out to establish relationships between variables and draw conclusions. Descriptives such as frequencies, mean, standard deviations and cross tabulations were used to display the data before detailed analysis was done.

Tests of significance, specifically T-tests and Chi-Square (X^2) were used. P-values were instrumental in informing the results of this study. Significant differences were estimated using Duncan's multiple range tests in SPSS for windows. Significance difference was set at $p<0.05$. The degree of correlation (r) or association between continuous independent variables and dependent variables was measured by use of Karl Pearsons' coefficient, while spearman correlation was used between discrete variables.

Logistic regression model was used to predict factors that influenced biogas adoption and utilization. The model is used when the dependent variable is a dichotomy and the independent variables are of any type. It applies maximum likelihood estimation after transforming the dependent into a logit variable (Garson, 2008). It estimates the odds of a certain event occurring. The dependent variable is a logit, which is the natural log of the odds.

The model is given as;

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

$$\mathrm{p} = \frac{\mathrm{e}^{\mathrm{a+bX}}}{1+\mathrm{e}^{\mathrm{a+bx}}}$$

Where P is the probability of the event occurring, X are the independent variables, e is the base of the natural logarithm and a and b are the parameters of the model. The empirical form of the model used in the study is as follows:

$$\mathrm{Pr}\,Y = \frac{1}{1+e^{-(a+bX)}}$$

Y is the logit for the dependent variable. The logistic prediction equation for the present study was: Y = ln(odds(event)) = ln(prob(event)/prob(nonevent) = ln(prob(event/[1-prob(event)])

$$= b_0 + b_1x_1 + b_2x_2 + \cdots b_nx_n$$

Where b_0 is the constant with $X_1 \ldots X_n$ independent variables affecting the probability of adopting biogas technology and $b_1 \ldots b_n$ were the coefficients estimated. The dependent variable was modelled as: Y= Adoption of biogas technology = Pr Y; (1 = Household chooses to acquire and use biogas technology, 0 = otherwise).

Data from Focused Group Discussions was analyzed by transcribing a summary of the notes and drawing conclusions using Attribution Content Analysis method (Kripperndorf, 2004).

Analysis of variance (ANOVA) was used to analyse gas data and to bring out the difference in gas constituents concentration, between the various treatments (feed types). This was done using SAS computer software (SAS institute, 2004). Mean comparisons of quantitative dependent variables were done using general ANOVA. To determine whether existing differences among the means were statistically different, post hoc multiple comparisons using least significant difference (LSD) and the critical value of t was done. The significance level (alpha level) was set at 0.05. Where significant differences were found, standard error of difference (SED) of means was used to evaluate how the treatments differed from each other.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Social-economic and Demographic Characteristics of Respondents

A total of three hundred and twenty five (325) households formed the sample of this study, and information was obtained from them. Among these, 200 comprised of households that had adopted biogas technology (adopter households), while 125 households had not taken up the technology (non-adopter households). Table 1, 2, 3 and 4, shows the variables perceived to influence households' decision to adopt biogas energy. Adoption in this study is defined as the acquisition, installation and use of a family-sized biogas digester by a household. A household was considered to have adopted the technology if it owned a biogas plant that was operational, or had been in operation at any one particular time.

4.1.1 Family size

Majority of households (61.9% adopters and 66.7% non-adopters) had a family size of 2-5 members (Table 1). Only a few households had more than ten members. Chi-square test of association showed that there was no significant association in family size between adopter and non-adopter households (χ^2 = 0.811, df =2, P=0.667).

Table 1: Chi-square tests between family size for the adopters and non-adopter households

Family Size	**Adopters**		**Non-adopters**		**Total**		**Chi square (χ^2)**	**P value**	**df**
	N	%	N	%	N	%			
2-5	120	61.9	84	66.7	204	63.8	0.811 (ns)	0.667	2
6-9	66	34	38	30.2	104	32.5			
10-13	8	4.1	4	3.2	12	3.8			

Average family size was 5.3 and 4.9 for the adopter and non-adopter households respectively (Table 2). Independent T-test just like the chi-square test failed to reveal a statistically reliable difference in family size between adopter and non-adopter households (Table 3). Family size therefore did not play a role in determining whether a household adopted the technology or not, probably because labour for biogas operations was provided by external laborers, and consequently size of the household was not an important consideration in adoption.

Table 2: Comparison of means for stated parameters between adopter and non-adopter HHS

Variable	**Adopters**			**Non-adopters**		
	Mean	**Std. Deviation**	**Std. Error of Mean**	**Mean**	**Std. Deviation**	**Std. Error of Mean**
Family size	5.30	1.98	0.14	4.98	1.75	0.16
Farm Size	2.24	1.88	0.15	1.78	1.65	0.16
Age of Household Head (Yrs)	53.4	10.7	0.79	47.1	11.5	1.04
Children below 5 years	1.60	1.37	0.20	1.43	0.68	0.11
Number of People Living in the Household	4.49	1.89	0.13	4.30	1.66	0.15
Number of Cattle	9.20	7.40	0.52	5.19	4.34	0.42

4.1.2: Farm Size

Average land size was 2.24 acres and 1.78 acres for the adopter and non-adopter households respectively (Table 2). Most adopter households (68.3%) and non-adopter households (78.2%) were found to own between 0.1- 1.0 acre pieces of land (Table 4). Only about 30% of adopter households owned more than 1 acre pieces of land.

Nonetheless, a notable proportion of the respondents owned relatively bigger chunks of land, of up to 12 acres

Statistical analysis revealed that farm size played a significant role in influencing adoption of biogas. Specifically, the Leuvens' test for equality of variances (t-test), revealed a statistically reliable difference in farm size between adopter and non-adopter households (t=2.080, p=0.038) (Table 3). This could be explained by several interacting factors. Large pieces of land owned could be an indicator of wealth, and by extension indicate that biogas ownership is mostly by the well up farmers who could afford the relatively high installation costs. Additionally, the relatively big land size could imply that owners are able to grow more fodder crops on bigger parcels of land and therefore rear a bigger heard of cattle, which yields more dung for biogas production.

Table 3 Household Characteristics of Respondents

Farm Characteristics	**Adopters**		**Non-adopters**		**Total**		**Chi square (χ^2)**	**P value**
	N	%	N	%	N	%		
Farm Size (Acres)								
0.1-1.0	112	68.3	86	78.2	112	68.3	2.08 (s)	0.038
2.1-3	23	14	14	12.7	23	14		
3.1-4.0	18	11	5	4.5	18	11		
4.1-12	11	6.7	5	4.5	11	6.7		
Type of House								
Mud	0	0	3	2.7	3	1	64.36 (s)	≤0.001
Timber	38	19.6	69	62.2	107	35.1		
Stone	156	80.4	39	35.1	195	63.9		
Type of Roof								
Iron Sheets	119	93	119	93	265	80.8	19.87 (s)	P≤0.001
Bricks	9	7	9	7	63	19.2		

It can also be argued that households with a large farm size have a higher probability of adopting biogas, since a large area can accommodate and integrate the bio-digester, the animal unit and fodder component in close proximity, helping feedstock collection to the bio-digester and monitoring of routine operations. Brush and Taylor, empirical study of 1992, showed a positive association between farm size and the extent of biogas adoption. The smaller the farm, the lower is the diversification of land use, as competition and conflicts arises.

4.1.3 Type of House, Roofing and Access to Electricity

Type of house was a big determinant in biogas adoption. χ^2 was highly significant at 64.36 and a P value ≤ 0.001 (Table 4 above). Most of adopter households (80.4%) had permanent stone-walled houses, with none in this group (adopters) having mud-walled houses. On the contrary, a big percentage (62.2%) of the non-adopter households had semi-permanent timber houses, with only 35% having stone-walled houses.

It was further observed that just like in the type of house, there was a close association between house roof type and biogas adoption. Though most of the roofing was by iron sheet, there was a notable discrepancy in brick roofing between adopter households (26.9%) and only a 7% non-adopter households ($\chi^2 = 19.87$, $P \leq 0.001$) (Table 4). The type of toilet too had a strong positive association with adoption. Majority of non-adopters (82.5%) used traditional pit latrines, with only 7% using modern flash toilets, while only 39.4% of adopter households used pit latrines.

Further, most respondent households had access to electricity from the national grid; 69.3% and 96.5% non-adopter and adopter households respectively. In-depth statistical analysis revealed the existence of a very close relationship between access to electricity and biogas adoption (χ^2 =47.019, P≤0.001). Only 3.5% of the adopters lacked access to electricity, compared to 31% non-adopter households.

These parameters; access to electricity, type of house and roofing, and toilet type are useful proxy indicators for wealth. Since they all had a significant positive relationship with biogas energy adoption, this served as indication that adoption of the technology was a preserve of the more wealthy and affluent members of the community. The more wealthy a household was, the greater was the likelihood for biogas adoption

4.1.3 Age, Education, and Gender

Table 4: Age, education level and gender of household heads

Demographic Variables	**Adopters**		**Non-adopters**		**Total**		**Chi square (χ^2)**	**P value**
	N	**%**	**N**	**%**	**N**	**%**		
Age (Yrs)*								
21-40	24	13.3	39	32	63	20.8	19.41 (s)	≤0.001
41-60	114	63	70	57.4	184	60.7		
61-80	43	23.8	13	10.7	56	18.5		
Gender*								
Male	157	87.7	106	83.5	263	85.9	1.108 (ns)	0.292
Female	22	12.3	21	16.5	43	14.1		
Education Level*								
Primary	48	29.1	35	33	83	30.6	2.211 (ns)	0.331
Secondary	66	40	47	44.3	113	41.7		
Tertiary	51	30.9	24	22.6	75	27.7		

* Of the Household Head

More than often, the household head was responsible over households' decisions, and therefore biogas technology adoption decisions. Age, education, marital status and gender of heads of households' were investigated

Most household heads (63% in adopter households and 57% in non-adopter households) were found to be in the age bracket 41 to 60 years. A further 10% of the adopter households fell between 20 - 40 years, and only 1% had reached 80 years and above (Table 4). Mean age of the adopter household heads (53.4 years) differed significantly with the mean age of non-adopter household heads (47.1 years) (Table 2).

Age can therefore be argued to have been a key factor influencing biogas adoption (χ^2 =19.41, $P \leq 0.001$). The fact that most adopter households heads were in the age bracket 41 to 60 years, can be related with the more productive age in the society (prime age), an age bracket comprised of community members who are likely to be employed in the formal and informal sectors, and therefore likely to have an income, and possibly some savings, and hence were able to afford the relatively high biogas installation costs. The youthful; 20 - 40 years (13.3%) and the elderly; above 80 years (1%) did not seem interested in the technology adoption as depicted by the low percentages. While the youthful heads of households perhaps did not have sufficient savings to acquire the technology, the elderly members of the community were probably more risk reluctant, and hence less likely to welcome innovation, and consequently a lower likelihood of adopting new technology

With reference to gender, most households were male headed both for adopters (87.7%) and non-adopters (83.5%) and only 14% of households were female headed. Contrary to the working hypothesis, gender of the household head did not have a significant relationship with adoption (χ^2 =1.108, P=0.292) (Table 5). This agrees with the results of Walekhwa *et al., (*2009); which showed that gender influence on the decision to adopt was not statistically significant. Since women dominate rural energy use at household level, it would be expected that households headed by females, would more easily take up and use the technology, thereby giving gender a positive influence to adoption. On the contrary however, whether households were male or female headed, did not influence a household in taking up the technology.

4.1.4 Household Occupation and Income Levels

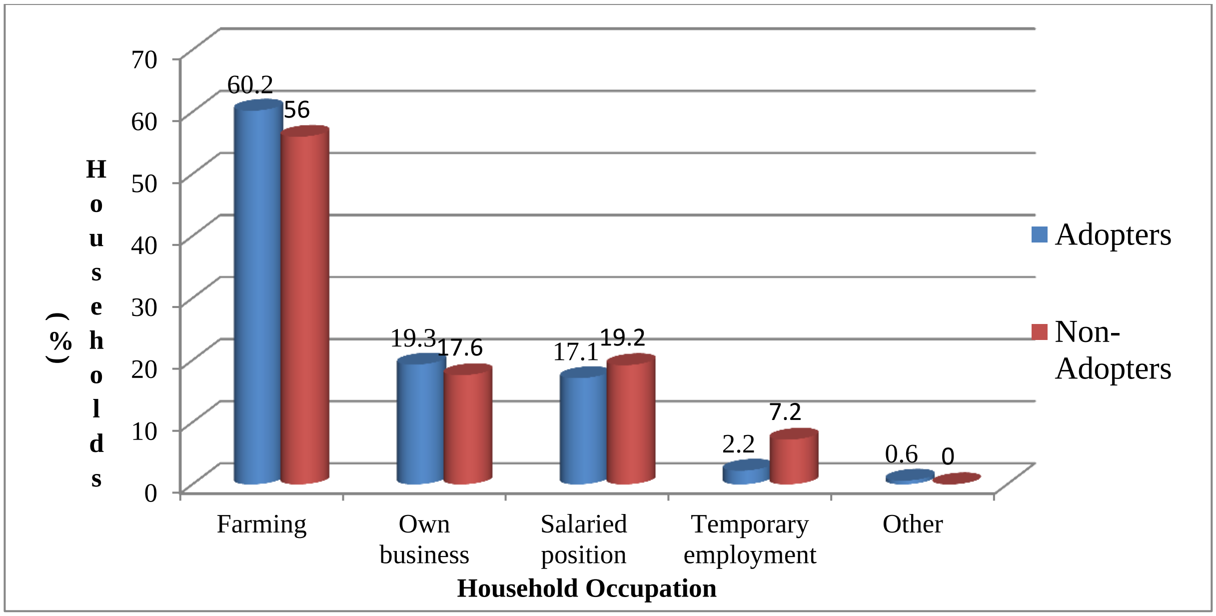


Figure 4: Livelihood options and sources of income for both adopter and non-adopter households

Though farm sizes in the study area were relatively small; less than 1 acre, as earlier shown, majority of residents depended on farming for their livelihood with 69% adopters and 56% non-adopters reporting farming (crop and animal) as their main source of income. Other occupations include owning business, salaried employment and temporal casual employment (Figure 4).

Household monthly income was found not to be closely associated with biogas technology adoption. Tests of association showed poor non-significant relationship between adoption and household income (χ^2 =3.423, P=0.181). Majority of households earned up to 50,000 KShs monthly (70.4 % and 79.2% adopter and non-adopter households respectively) (Figure 5). Only very few respondents, less than 1%, earned more than 100,000 KShs.

The lack of significant relationship between biogas adoption and average monthly income can perhaps be explained by the fact that the technology required only a one-time investment during the installation phase (when a minimum KShs 55,000 was required), and very minimal maintenance costs through post-installation.

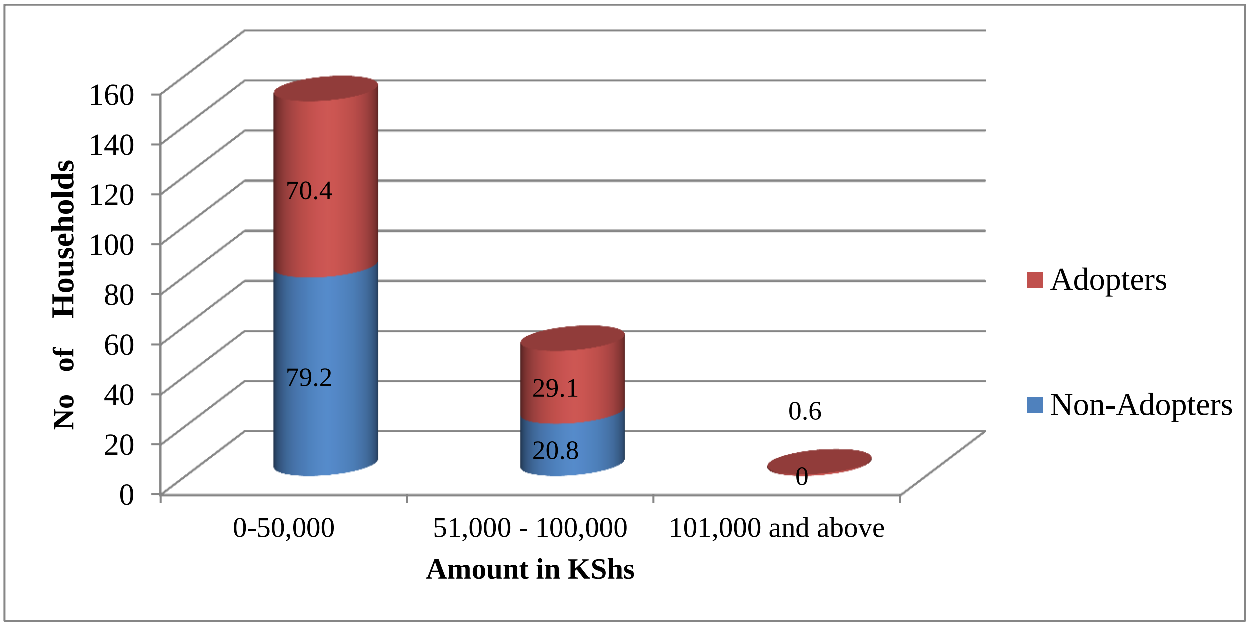


Figure 5: Income levels for adopter and non-adopter households

Therefore, one can argue that households did not have to have a regular income to own the technology, as long as they were able to raise the initial installation costs. This contradicts findings by Gupta and Ravindranath (1996), which showed that household incomes positively influenced households' decision to consume biogas energy. In their study, they emphasized the importance of households' income in the choice of cooking fuels. The technology initial investment normally is perceived too high for rural households to afford, and as such, biogas plants are considered preserves of the relatively wealthier households.

The results also contradict the energy ladder hypothesis (Greg and Hovorka, 2008), which assumes a transition to modern fuels as income rises. Thus, increasing incomes would be expected to see a rise in biogas adoption, and a gradual departure from firewood use, a scenario that this study has not demonstrated. Gupta and Köhlin (2006) show that it is not only price that influences the transition from wood to modern fuels, but also convenience and the reliability of supplies**.**

4.1.5. Livestock Ownership and Management

Cattle rearing was most dominant and ran across both adopters and non-adopters. Poultry, goats, sheep and pigs followed in abundance in that order. Cattle management regime was predominantly by zero-grazing (97%), while free-range, tethering and others were reported at 3%, 1.5% and 2% respectively. Respondents, both adopters and non-adopters owned a variety of livestock (Table 5).

Feed types for the cattle was diverse and included among others, Napier grass and other crop residues, dairy meal and pig feed from shops (commercial feed concentrates), brewers' grains (by-product from beer production), molasses and silage among others.

Table 5: Livestock type and abundance among biogas adopters and non-adopters

Type of Livestock	Adopters				Non-adopters			
	N	Mean	Std Deviation	Std. Error of Mean	N	Mean	Std Deviation	Std. Error of Mean
Cattle	196	9.19	7.454	0.532	109	5.19	4.341	0.416
Pigs	22	15.12	10.03	2.139	8	14.3	10.23	3.619
Poultry	94	138.8	383.4	39.54	71	36.7	79.48	9.432
Sheep	30	4.500	3.748	0.684	18	7.44	9.275	2.186
Goats	37	3.513	2.116	0.347	22	4.82	3.633	0.774
Donkeys	17	3.647	6.061	1.470	8	1.13	0.353	0.125

Feeding in most households comprised of two or three combination of the named feeds. Feed concentrates (dairy meal and wheat bran), Napier grass and farm residues were the most popular both for the adopters and non-adopters (Figure 6). Importantly, the number of cattle the household owned was highly important in influencing adoption. Adopter households were found to have more number of cattle in comparison to the non-adopter households. Mean number of cattle was 9.2 animals for the adopter households, compared to 5.2 animals for the non-adopter households (Table 5).

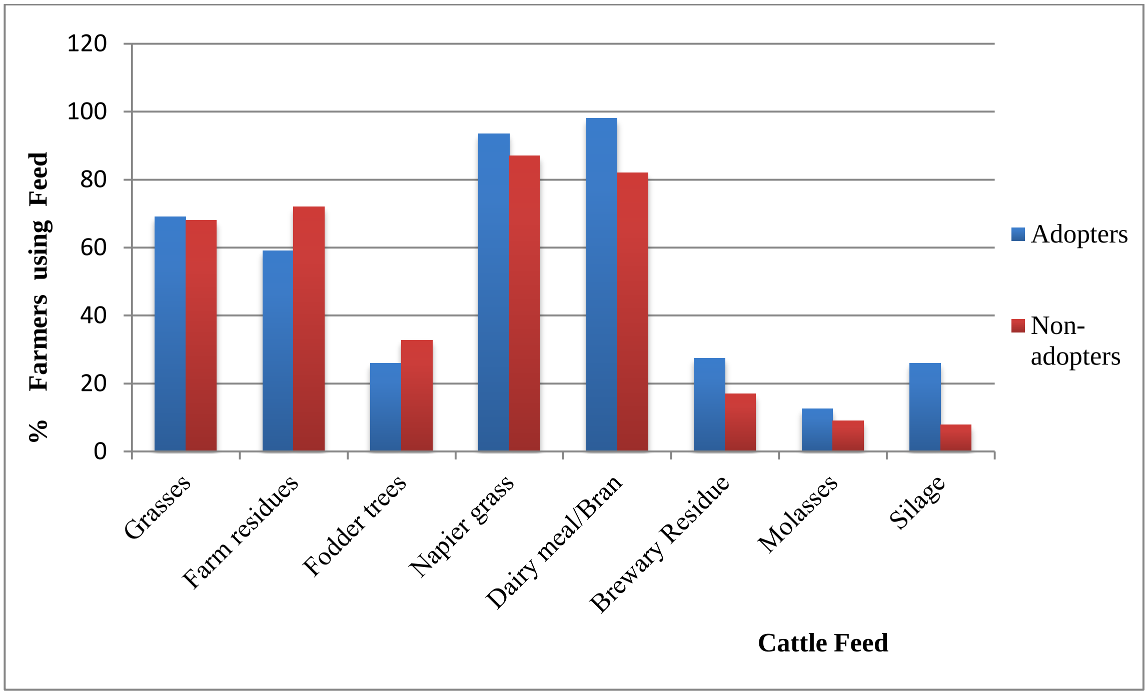


Figure 6: Cattle feed type and number of farmers using to feed their cattle

Chi-square tests further revealed that the more the number of cows the household had, the more the probability that they were likely to adopt biogas technology (χ^2=12.29, P=0.006) (Table 6). This observation could perhaps be explained by the recognition that many cattle would lead to production of huge quantities of dung, the raw material, required in biogas production, and therefore ensure sustainability of the technology. Adoption decisions were perhaps easier for households with big number of cattle, compared to those that owned small herds. The understanding of dung requirements for gas production might have made households with fewer cows shy away from taking up the technology. The number of cattle owned was a useful indicator of the availability of feedstock for the digesters. This could be particularly true since other types of feedstock, such as crop residues, household waste and human waste have not been fully explored in the region (Onduru *et al.,* 2009).

Table 6: Number of cattle owned by adopting and non-adopting households

Number of Cows	**Adopters**		**Non-adopters**		**Total**		**Chi square (χ^2)**	**P value**
	N	**%**	**N**	**%**	**N**	**%**		
1-10	112	68.3	86	78.2	112 68.3		12.29(s)	0.006
11-20	23	14	14	12.7	23	14		
21-30	18	11	5	4.5	18	11		
31-40	11	6.7	5	4.5	11	6.7		

A large heard of cattle could also mean that returns from sale of milk would perhaps be high; and therefore the household would have extra finances for hiring labour needed in biogas operations and maintenance, and generally in the overall technology investment.

4.1.6 Household Characteristics Predicting Biogas Technology Adoption

To validate the above noted observations, a logistic regression analysis was conducted to predict adoption of the technology for the 350 households. Family size, farm size, age, education and gender of the household head, and the number of cows owned were fitted in the model as predictors. A test of the full model against a constant only model was statistically significant, ($\chi^2 = 37.44$, $P \leq 0.001$, df =6), indicating that the predictors as a set reliably distinguished between adopters and non-adopters of the technology (Table 7). In other words, the estimated values fitted the observed data reasonably well. Measures of goodness of fit of the model results indicated that the independent variables were simultaneously related to the log odds of adoption.

Table 7: Binomial Logistic Regression Estimates of Biogas Adoption Model in Kiambu –
Factors likely to influence biogas technology adoption

Predictor Variables	**B**	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**
Family size⋆	.072	.085	.716	1	.397	1.075
Farm size ⋆⋆⋆	.128	.107	1.438	1	.030	1.137
Age of HH head (Yrs) ⋆⋆⋆	.050	.017	8.667	1	.003	1.052
Education of HH head⋆⋆⋆	.609	.245	6.186	1	.013	1.839
Gender of HH head⋆	-.764	.468	2.663	1	.103	.466
Number of Cattle⋆⋆⋆	.123	.040	9.553	1	.002	1.131
Constant	-3.708	1.306	8.067	1	.005	.025

Correctly predicted adoption 88.3%,
Correctly predicted non-adoption 45.8%,
Overall percentage predicted 73.0%
Chi-Square (X^2) = 37.44, P ≤ 0.001, df =6
Cox and Snell R square 0.171
*Not statistically significant**
Statistically significant ⋆⋆⋆
HH – Household Head

The model had a good explanatory power with prediction success overall of 73.0% (88.3% for adopters and 45.8% for non-adopter households). That is, the independent variables chosen correctly predicted household biogas adoption conditions for 73% of the total observations. Among the six variable included in the model, the Wald test results for four of these indicated that they had a statistically significant influence on biogas adoption.

The Wald criterion demonstrated that age (β=0.05, P=0.003) and education levels (β=0.609, P=0.013) of the household head, farm size and the number of cattle owned (β=0.123, P=0.002) made a significant contribution to biogas technology adoption, while family size, and gender of the household head were not significant in influencing prediction of adoption (Table 8). There was thus a great likelihood that a combination of the independent variables; age, education level, size of farm and number of cattle owned, led to adoption of the technology by the household.

The logistic model results just like the Pearson chi-square results presented earlier, reveal that households' characteristics form the core of the reasons why rural home choose to adopt or not to adopt the technology. Contrary to a wide misconception that a lack of adoption may be due to technological constraints, the present results clearly shows that the social-economic characteristics of rural households to a large extent are important in determining whether a household takes up a technology or not, and therefore in up and out-scaling of biogas technology. Mendola (2007) acknowledges that the development and management of biogas innovations is far from a purely technical question, and almost always involves numerous economic and social problems, as well as human behavior. Indeed, characteristics of households could be a single most important factor, why households choose to adopt or not.

Overall, this study found out that age of household head of the adopter households had a significant positive relationship with biogas technology adoption. The probability of household adopting the technology was higher in households where the heads were middle aged to elderly, compared to those headed by youths (elderly in this case was 61 to 80 years and youth was 21 to 40 years). This result contradicts findings by Somda *et al.,* 2002, who found that the farmers' age was negatively related to adoption. Similarly, and in line with the hypothesis, the model results also points out that education level of the household head too had a significant positive relationship with adoption. The likelihood to adopt increased by a factor of 1.839 (Table 8) with advancement in education. This is attributed to the fact that perhaps low literacy levels would hinder information absorption needed for substantive decision making on new technologies. More than 70% of adopters had attained secondary and tertiary education, and this is considered reasonably sufficient for individuals to be able to make informed decisions on an unfamiliar innovation. The results agrees very well with adoption studies by Kebede *et al*., 1990; Brush and Taylor, 1992; Adesina and Baidou Forson, 1995 and Fleke and Zegeye 2006; which all revealed a positive correlation between education and probability of adopting new technology. Mwakaje, (2008), argues that low education levels is one of the constrains to adoption of biogas technology in Africa. Additionally, more educated people would be expected to be less conservative, more exposed to sources of information, and therefore more informed, knowledgeable, and environmentally aware about the harmful effects of firewood use on family health, and environment.

Gender of household head was expected to have either a positive or negative effect, since gender relationships regarding male female asset ownership and control in Africa, influence key decisions regarding technology uptake. Since women dominate rural energy use at house household level (Karekezi, 2002), it can be expected that households headed by women could have a higher probability of adopting biogas energy than their male counterparts. In the current study as depicted by the model however, and contrary to the hypothesis, gender had a negative non-significant (P=0.103) relationship with biogas adoption. With an odds ratio of 0.466 and a logit coefficient of -0.76, gender of the household head did not appear to influence biogas adoption. This meant that households headed by either gender were not any differently constrained in biogas adoption compared to the other gender. High education levels by women in the area just like by the male counterparts could be the reason for this observation. Highly educated female heads of households are more likely to make technology adoption decisions, just like in male headed households. This is a very crucial and significant revelation in biogas uptake campaigns, since it illuminates women as equal and important players, just like their male counterparts in biogas adoption.

It is evident from the findings presented that biogas technology adoption and use was a result of a complex set of interaction between the technology and the user social economic characteristics. Dorfan (1996) observes that a household derives utility from choosing a particular option, given its resource endowment and observable attributes. Existing literature on adoption behavior concurs that social, personal, physical, economic and institutional factors are key determinants of the adoption process (Adesina and Baiduforson, 1995; Drake *et al*., 1999; Kassenga 1997; Somda *et al*., 2002; Bekele and Drake, 2003).

4.1.7 Motivation and Reasons for Installation of Biogas

Respondents were asked to give the main motivating reasons for acquisition and use of biogas plants. Economic and environmental benefits were the most important reasons. Majority of biogas adopters were inspired by the fact that biogas is clean energy and produces no smoke (61%), helps save other fuels (77.3%), and it is affordable (55%) (Table 8). Table 8: Motivating reasons for farmers to install biogas technology

Motivation	**Responses**		
	N	**%**	**Rank**
Cooks quickly	154	77.0	1
Saves fuel	153	77.0	2
Economic benefits	146	73.0	3
Environmental benefits	125	62.5	4
Produces no smoke	122	61.0	5
Health benefits	72	36.0	6
Affordable	55	27.5	7
Access to subsidy	51	15.5	8
Social benefits/Prestige	33	16.5	9
It makes use of farm wastes	22	11.0	10
Durable	19	9.50	11
Motivation from neighbors	15	7.50	12
Motivation from service provider	7	3.50	13
Non-availability of other fuels	3	1.50	14
Others	3	1.50	15

Respondents were asked to give the main motivating reasons for acquisition and use of biogas plants. Economic and environmental benefits were the most important reasons. Majority of biogas adopters were inspired by the fact that biogas is clean energy and produces no smoke (61%), helps save other fuels (77.3%), and it is affordable (55%) (Table 8). The ability of biogas technology to cook quickly and save valuable time received an overwhelmingly support from 77% of the respondents while health benefits associated with it scored a notable 30%.

It is interesting to note that only a minority 3% were motivated to install biogas because there was no other fuel type available. This points out that though other fuel forms would have been available, there were other reasons enough to inspire installation and use biogas energy. Only 25% installed because of price subsidy availability. When asked their preference for biogas fuel relative to firewood, 50% reported that biogas does not produce smoke and provides clean cooking environment, which eliminates the need to have a separate kitchen house, and cooking can easily be done in the main house. A further 48% reported their preference for biogas since it is an instant energy, and saves them lots of time that would otherwise be spent in gathering firewood. Approximately 15% preferred biogas because it is modern energy and would lift their social status in the community, while a staggering 1% had its preference because it resonates well with their culture and traditions.

The findings agree with the study by InforWit Research Consultants (2013), in Kenya, which found out that the main reasons for involvement in biogas production and use were; the need to have an alternative sustainable source of fuel, environmental conservation and economic reasons. In Ghana unlike in Kenya, improved sanitation was the main motivating reason for installation and use of biogas plants (Edem and Abeeku, 2010). The ability of the bio-digester to treat animal dung (sewage) and avoid the need for septic tanks was reason enough for adoption of the technology. In Pakistan, about 20% of users were motivated by the fact that bio-digesters were comfortable and easy to operate, 15% by time and energy savings, and 12% to avoid indoor smoke. Slightly over 20% were motivated because of the subsidy given by project promoters (Waqar *et al*., 2013). This is in line with the findings of the current study.

4.2 Biogas Adoption: Installation, Operation and Use

4.2.1 Types, sizes and distribution of biogas in Kiambu

Two major types (designs) of biogas digesters (*Fixed dome* and the *Floating drum*) were found to be the most prevalent (52% and 44% respectively) in Kiambu (Figure 7), while a third type; *Tubular*, was not very common (4%). The three (Figure 8; Plates 1a, b & c) are small-scale digesters, and are commonly referred to as family size digesters (Kandpal *et al.*, 1991; Singh and Sooch, 2004). These were found to be spread across the entire study villages of Githunguri, Lari, Kikuyu, Ndumberi and Limuru, without any evident trend.

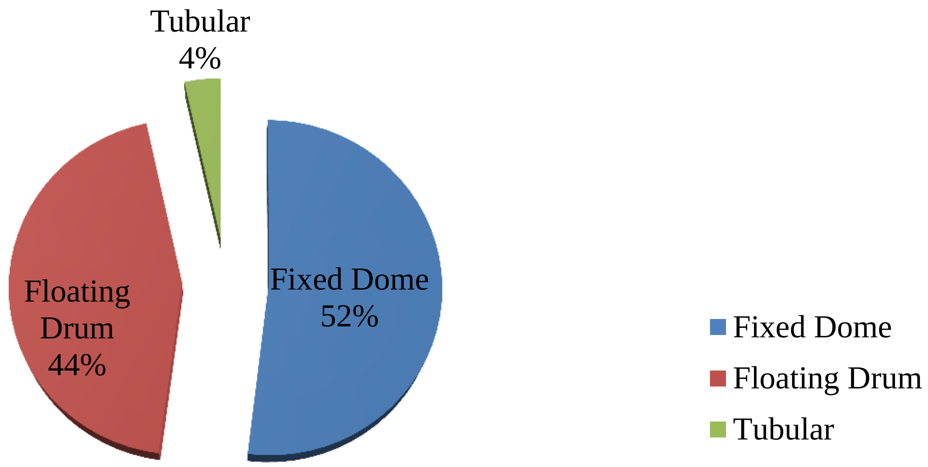
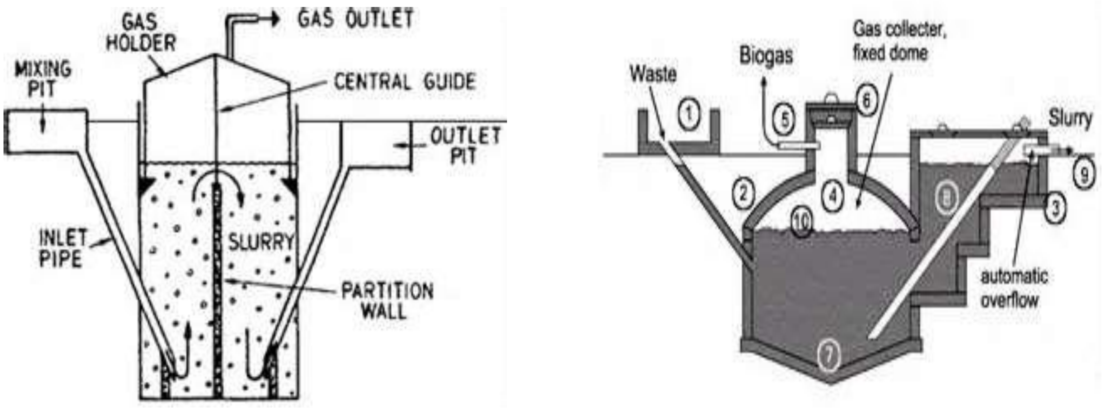


Figure 7: Types of biogas digesters and their relative abundance in Kiambu County (Field Survey, 2011)

Three models of the fixed dome existed and they included; AKUT by German Organization for Technical Cooperation (GTZ), KENBIM by Kenya National Domestic Biogas Programme (KENDBIP) and CARMATECH by Sustainable Community Development Services (SCODE). Their design is essentially the same, heavily borrowed from the Chinese model, and only a difference in brand name, which is of particular significance in the identity of the builder or promoter.

A small proportion of the respondent population, 4%, had installed *Tubular* type of digesters, which is a plastic tube with an inlet on one side, and an outlet on the other (Plate 1c). Sizes of the digesters across the fixed dome and the floating drum varied from 4, 6, 8, 10, 12, 16, 18, 24 and 32 cubic meters, while the tubular one came in 4, 6, 8 and 10 cubic meters. The size depended on several interacting factors, which include; the size of the household, and gas volumes requirements, capital and space availability, availability of substrate, and the economic investment capabilities of the household among other factors.

The 16m^3 sized digester was the most widely installed, while 18m^3, 24m^3, 32m^3 and 4m^3 digesters were the least populous; 05%, 2.5%, 5.6% and 6.1% in that order. The fact that only few farmers had installed 4m^3 digester can perhaps be explained by gas yield potential of such size vis a vis household gas requirements. A probable explanation of similar observation with the bigger digester sizes (24 and 32 m^3) could be due to the high installation/material cost needed and the dung (substrate) amount requirements to sustain gas production in such size. Shakya in his study of 2005, could not over-emphasize substrate availability in bio-digester size decisions. He illustrated that two cows can only sustain a 4m^3, 4 cows a 6m^3 and 6 cows a 8m^3 digester. Singh and Sooch (2004) contend that selecting the size of biogas plant to be installed depends upon the number of persons to be served or the quantity of cow dung available, and stresses that selection of unsuitable bio-digester capacity that does not match the availability of the cow dung, renders the biogas technology uneconomical.



a) Floating drum biogas digester (Frankel, 1986) *b) Fixed dome biogas digester (Frankel, 1986)*

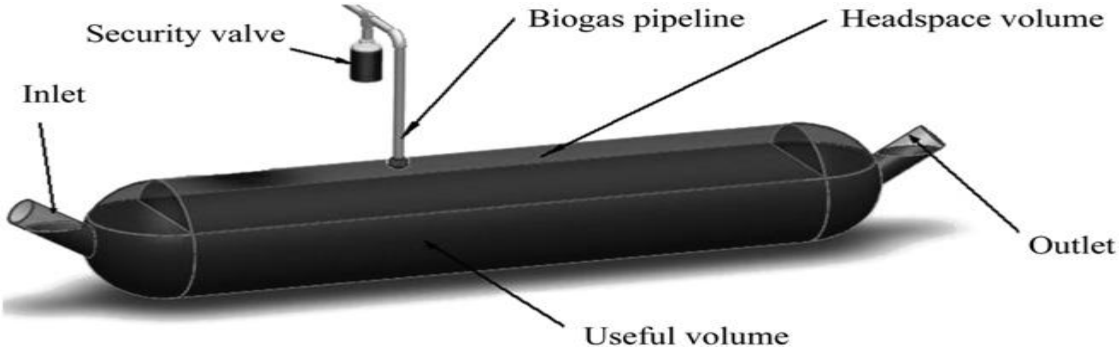


Figure 8. Schematic representation of floating drum, fixed dome and tubular family-sized biogas plants (Singh and Sooch, 2004)

c) Tubular biogas digester (FAO, 1996)

a) Floating drum biogas *b) Fixed dome biogas digester* *c) Tubular biogas digester*

Plates 1a, b &c. Pictorial representation of family-sized biogas plants in Kiambu (Field Survey 2011).

4.2.2 Biogas Awareness and Installation Decisions for Adopter and Non-adopter Households

As shown in Table 9, existing biogas users (friends and neighbors) served as the main source of information on biogas technology (74%) for the adopters. Awareness campaigns by development organizations (NGOs) and mass media (mainly TV and radio) reached 18% and 14% households respectively. It was only about 9% biogas users who became aware about the technology through exhibitions, while less than 1% learned from hardware stores.

Table 9: Sources of information about biogas technology

Source of information	**Adopters**		**Non Adopters**		
	N	**%**	**N**	**%**	**Rank**
Friends/Neighbours	148	74	86	55.5	1
Government/NGO	36	18	27	17.4	2
TV/Radio	28	14	26	16.8	3
Exhibition/Promotion	18	9	15	9.7	4
Relatives	7	3.5	-	-	5
Hardware/Supermarket	1	0.5	1	0.6	6

The biggest percentage that got to learn from counterpart users indicates the potential of existing technology users as tool for promotion and extension. Probably why most new adopters learned from existing adopters is the power of actual demonstration. Potential users are able to see and appreciate real benefits, and thus get inspired to replicate what they have seen. This is in line with the diffusion of innovation theory (Rodgers, 1995), which predicts that media as well as interpersonal contacts, in addition to providing information, influences opinion and judgment.

Installation decisions were made mostly by the household heads, 64.2% being males and 32.5% females. Children did not influence installation decisions. In a few households, 2.6% joint decisions were made between husband and wife.

Majority of the non-adopter households sampled (93%), were aware about the technology. Just like in the case of adopter households, the non-adopter farmers had learnt about the technology mainly from neighbours (56%), who had installed and were already using, government and non-government agencies (17.4%), and mass media (16.8%). Outlet stores for biogas related materials did not seem to play a significant role in informing farmers. The big question then is why these community members chose not to own biogas plants, yet they were aware of the technology. Diverse response for not adopting the technology is given in Table 10.

Table 10: Non-adopter households' reasons for not adopting the technology

Reason for not owning Biogas	**N**	**%**	**Rank**
Expensive	95	44.6	1
Requires too much waste	39	18.3	2
Requires too much labour and attention	29	13.6	3
Not aware of it /lack of information	14	6.6	4
Do not know how it works	12	5.6	5
It spoils quickly/frequently	9	4.2	6
Gas leakages and fire accidents	2	0.9	7
It cooks slowly	1	0.5	8

Cost of acquisition and installation of the technology was identified as the biggest limiting factor with 44.6% of non-adopter households' respondents reporting that the technology was expensive, and they could not raise the required initial capital. This agrees with an observation by Barnes *et al.*, 1997, that in developing countries, initial costs of access to modern energy sources are often prohibitive for poor rural populations who in general are not willing to obtain credit. Other limitations to adoption cited include; high labour (14%) and substrate (18%) requirements, and lack of knowledge on biogas operations and use (6.6%) (Table 11).

4.2.3 Costs and Financing of Biogas Plants

Majority of biogas users financed their plants mainly from own savings (74.5%), while 25.5% got subsidy (KShs 25,000) from technology promoters. About 29% got loans from various sources; banks (30%), savings and credit cooperative societies (SACCOS) (41%), micro-finance institutions (9%), and friends (21%).

Actual cost of the digester depended on the size and type of the digester (Table 11). A high positive correlation (0.88, $P \leq 0.01$) between digester size and cost was revealed. The bigger the size, the high was the cost, and this was attributed to the cost of construction materials. Overall, the Fixed-dome model seemed to be relatively expensive compared to other models. For instance, the average cost of a $4m^3$ sized digester across the three different models; was KShs 58,123 for the Fixed Dome, compared to KShs 50,000 under Floating Drum, and KShs 25,000 for the Tubular digester. A $10m^3$ sized Fixed Dome costed KShs 19,583 and KShs 37,083 more than the same size of Floating Drum and Tubular respectively.

Comparatively, the tubular design, often referred as low-cost digester was the least expensive with a $10m^3$ digester costing KShs 65,000. Despite this however, only 4% of respondents had installed this digester type. Respondents cited durability and 'safety-on-compound' reasons, for the low count of the tubular type where the fixed dome and the floating drum are considered more long lasting and protected, due to the construction materials used (cement and metal sheets), and also the design of construction. The fixed dome is held underneath in the ground and covered with soil, while the metal drum in the floating drum is sunk in a concrete tank.

Table 11: Biogas Digester by Types and Sizes and their Costs

Type of Digester	Size (m^3)	Average Cost in KSHs (Mean)	N	Standard Deviation
Fixed Dome	4	58,125	8	15,797
	6	70,176	17	7,740
	8	80,185	27	12,518
	10	102,083	12	11,572
	12	120,500	14	17,965
	16	130,000	20	13,860
	18	145,000	1	
	24	160,000	1	
Floating Drum	4	50,000	3	10,000
	6	55,556	9	11,024
	8	75,000	10	11,055
	10	92,500	8	30,938
	12	115,294	17	19,880
	16	120,523	22	31,370
	24	150,000	4	21,602
	32	225,556	9	25,427
Tubular	4	25,000	1	
	6	40,000	2	7,071
	8	51,667	3	2,887
	10	65,000	1	

Another reason given is that the Tubular type is more vulnerable to prevailing weather conditions since it is much exposed to the outside environment, and therefore respondents feared that gas production could be negatively affected (low yield) during cold weather seasons. Since the plastic tube is only laid on the ground, its susceptibility to vandalism and damage by livestock and wild animals could be another factor leading to its low adoption.

The largest investment in biogas technology was incurred mainly during the construction stage, and thereafter very minimal repair and maintenance costs were expended. Initial outlay expenditure includes cost of building stones, ballast, cement, pipings, valves and fittings, metal sheets, gas stoves; and masons fee (labour), which all inclusive made the technology be relatively expensive. Other expenditure was on labour for feeding the plant with slurry, which on average did not exceed KShs 2,000 monthly in most households. By and large, installation costs took the bulk of the total costs, and this was a big limiting factor to technology adoption. When asked their opinion on the overall technology costs, most adopters (79%) said they found it affordable, 6.7 % found it very cheap and only 1.5 % found the cost to be very expensive. This observation could be interpreted to reflect that though the installation costs are relatively high, the long-term benefits override the installation costs.

4.2.4. Gas Production and Use

Of the 200 biogas plants that had been installed, 189 were still functional when the study was being conducted. Cattle dung was the main substrate for dung production and only about 2 % respondents used farm biomass as substrate.

Table 12: Major uses of biogas energy by households

Use of Biogas	**Yes**		**No**		**Total**	
	N	**%**	**N**	**%**	**N**	**%**
Cooking	190	98.4	3	1.6	193	100
Lighting	20	10.4	172	89.6	192	100
Light industries/Driving machines	5	2.6	187	97.4	192	100

Of the 200 biogas plants that had been installed, 189 were still functional when the study was being conducted. Cattle dung was the main substrate for dung production and only about 2 % respondents used farm biomass as substrate. The gas produced was mainly used for household cooking (98%) (Table 12). Users were satisfied with the biogas mainly because of the myriad of benefits it offered. In addition to energy provision, economic and health benefits and ease of cooking were mostly cited by respondents (Table 13). About 85.5% reported that the gas yield was sufficient for their uses, while 73% said they were able to save money. The ease of use (instant energy that does not have drudgery in lighting), and production of no smoke makes the technology more appealing to the users. Environmental benefits of conserving trees made 43% respondents satisfied with the technology.

Table 13: Biogas attributes that made users satisfied with the technology

Reasons for satisfaction with the biogas fuel	N	%	Rank
Provides enough gas for cooking	147	85.5	1
Economic benefit e.g. saving money	124	72.5	2
Easy cooking/lighting	103	60.2	3
No smoke	101	59.1	4
Environmental benefits (less firewood)	73	42.7	5
Social benefits (prestige)	44	25.6	6
Reduced workload	34	19.8	7
Cooks more tasty food	10	5.8	8

4.3 Household Fuel Consumption Patterns

4.3.1 Impact of Biogas Adoption on Fuel Type and Quantities

Biogas adopter households depended on a diverse range of fuels for cooking and lighting. Approximately, 90% of respondent households pointed out using firewood, charcoal and liquefied petroleum gas (LPG) for cooking, pre and post biogas installation. None of the households however relied on one type of fuel, but rather, a combination of fuels, and, or switch to different fuels to suit different uses. Notably, firewood was consumed more than any other fuel. However, there was marked reduction in fuel consumption by type and quantity after the installation of biogas (Table 14).

Average firewood consumption per month per household was estimated at 187.5 Kgs and 60.8 Kgs before and after installation of biogas respectively. This translated into monthly net reduction of 126.6 Kgs (67.5%), and this was highly significant as revealed by statistical analysis (t=18.71, P=0.001). In other words, use of biogas by an average household helped save about 1519.2 Kgs of firewood annually.

On average, charcoal consumption also reduced significantly (t=16.42, P=0.001) at 83.9%, with use of biogas. With an average monthly consumption of 114 Kgs before and 18.3 Kgs after the installation, households were able to save about 95.6 Kgs of charcoal monthly. Initially, a bag of charcoal (35 Kgs) was reported to last a household for only nine days before biogas acquisition and use, compared to 60 days (two months) after the installation. With 10 Kgs of wood needed to produce 1Kg of charcoal (Muller *et al*., 2011), 956 Kg of wood that would have gone into making charcoal to be used by an average household for one month was saved. By extrapolation therefore, substituting and, or supplementing charcoal with biogas helped save roughly 11.7 metric tonnes of wood per household annually.

Use of liquefy petroleum gas (LPG) too reduced by a very significant margin (P=0.001), coming down to literally nil with the use of biogas (Table 15). Average monthly consumption per household was at 7.5 litres before the installation and zero consumption upon biogas installation. This marked reduction (100%), is attributed to biogas energy, which tremendously reduced the need to purchase LPG, a fuel which is expensive, but essentially serves the same purpose as biogas in terms of fuel quality.

Table 14: Biogas adopter household energy consumption by type, before and after biogas installation

Type of Energy	Total fuel used monthly before installation of Biogas	Std Deviation	Total fuel used monthly after installation	Std Deviation	Mean Difference	t	Sig. (2-tailed)
Firewood in Kgs (N=179)	187.5	122.36	60.8	63.95	126.6	18.71	0.001
Charcoal(N=181)	114.0	85.83	18.3	30.68	95.6	16.42	0.001
Electricity(N=169) ***(in KShs)***	1746.9	1322.1	1567.2	1141	179.8	3.782	0.001
LPG(N=183)	7.5	7.26	0.0	0.00	7.5	14.01	0.001
Kerosene(N=187)	0.7	2.57	0.2	0.99	0.5	3.018	0.003

Kerosene use by most households, was minimal in both scenarios (pre and post installation), at less than a litre on average in a month per household. The mean difference between the two scenarios was estimated at 0.5 litres and this was statistically significant at P value of 0.003. The observed reduction in kerosene consumption (71.4%) can possibly be explained by the fact that before biogas was acquired, kerosene was perhaps used both for lighting and light-cooking (for example warming tea), and with the installation of biogas, the need to use kerosene for cooking diminished, and was perhaps set aside only for lighting in the evenings.

Electricity use was measured by proxy, using monthly payments, since the respondents could not recall the actual number of units consumed, and paper bills were also not available. Studies have indicated that electricity consumption do not differ significantly with the installation of biogas since it is assumed that electric power is used mostly for lighting, and biogas for cooking, and therefore even in the presence of biogas, electricity would still be in use to light houses at nights. On the contrary, this study has shown significant reduction in electricity consumption, with a mean difference of KShs 180 (t=3.78, P=0.001) after biogas installation (Table 9). This could be an indication that some households were using electricity for cooking before the installation, and perhaps this was taken over by biogas, leaving electricity only for lighting, and hence the significant reduction.

Overall, it is noted that traditional fuels consumption reduced tremendously with the installation of biogas. Worth noticing is the reduction in firewood and charcoal. The hypothetic assumption that using biogas would reduce firewood consumption by up to 50% in user households, revealed a 67.6 % reduction in firewood and 83.95 % reduction in charcoal use, with acquisition and use of biogas.

A study in Nepal by Winrock and Eco Securities (2004), found annual reduction of wood fuel at 2 tonnes per household, and this provided an equivalent protection of 6,790 hectares of forest per year through 11,395 operational biogas plants (Winrock and Eco Securities, 2004). According to Biogas Support Programme (BSP) of Nepal (2006), 97% of over 168,613 plants installed under the SNV/BSP programme, which were still operational by close of year 2007, helped displace the use of 328,000 tonnes of wood fuel, 5.2 million litres of kerosene and replaced chemical fertilizers with 280 thousand tonnes of bio-fertilizer annually. In addition, they helped save approximately 1850 ha of forest annually. Use of firewood reduced by 162 Kgs per month per household, and this was equivalent to 2 tonnes per household annually (CMS, 2007). A study in China (REN21, 2005), showed similar findings. Among families owning biogas digesters, per capita energy consumption reduced by 25%, while consumption of biomass (stalk and straw) reduced by 50%. In yet another study by Anushiya (2010), average annual wood fuel consumption for biogas households amounted to 1,820.48 kg per household. She found considerable saving of 2,122.6kg (53.83 %) of wood fuel per year per household. Comparing Biogas users before and after biogas installation, 54.8 % of wood fuel was saved on average A Study by Xiaohua *et al.* (2007) showed that biogas digesters, used in different regions of rural China, reduced the use of biomass fuel by 40% (Xiaohua *et al.*, 2007).

4.3.2 Comparison of Fuel Consumption for Biogas Adopter and Non-Adopter Households

Most non-adopter households heavily relied on firewood and charcoal for their domestic energy needs (Figure 9). Average monthly firewood consumption for non-adopter households was 228.5 Kgs, compared to an average of 187.5 Kgs consumed by biogas adopter households before the installation of biogas plants. About 82 Kgs of charcoal was consumed on average by non adopter households, and monthly payment for electricity consumed stood at KShs 1,094 on average. This too was low compared to KShs 1,746 paid by adopter households before they acquired and operationalized the technology. The amount of LPG consumed by the non-adopter households was same with that consumed by the adopter households' pre-installation phase, at 7.5 litres monthly. Of importance too to note is that contrary to the other fuels, kerosene consumption was relatively high for the non-adopter households (5.2 litres monthly), compared to 0.7 litres consumed by adopter households pre-installation phase.

Comparing fuel consumption for the non-adopter households and adopter households after biogas installation, the observable mean difference could not be over-emphasized. With the non-adopters using 228.5 Kgs of firewood monthly, biogas users consumed only 60.8 Kgs. The reduction in charcoal was also huge with the non-adopter households using 81.8kgs per month per household, vis a vis 18.3 Kgs consumed by households that have adopted biogas.

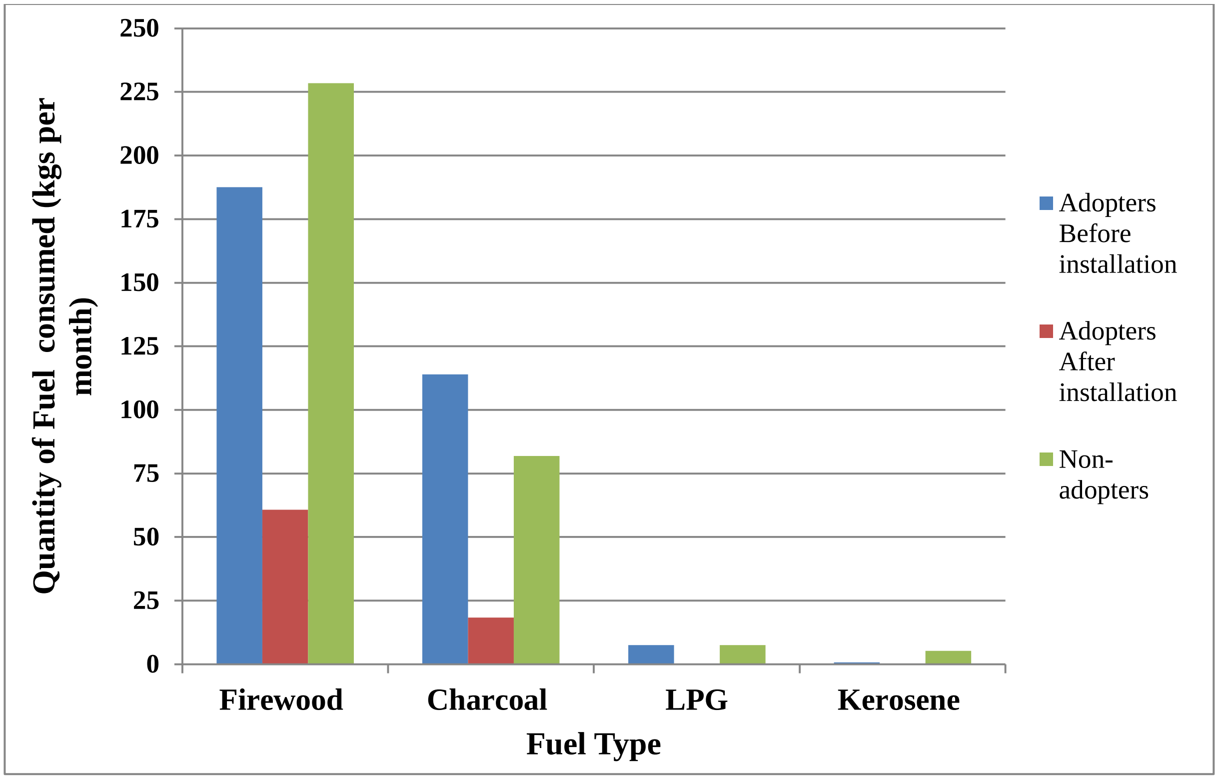


Figure 9: Comparison of fuel consumption between biogas and non-biogas households

Similarly, while the non-adopting households continued to use approximately 7.5 litres of LPG per month, biogas users did not use this fuel at all after the shift to biogas energy. These figures can then be used to confirm earlier argument and assertion that the change in fuel use by the technology adopter households was indeed as a result of biogas technology. Though fuel consumption by types and amounts between adopter and non-adopter households seemed to differ before biogas installation, the variance recorded in the same parameters with the adopter households after the installation of biogas was not only noticeable, but also highly significant (Table 14).

4.3.3 Estimated Equivalent Forest Area Protected from Reduced Fuel wood Consumption

Approximately, 1519.2 Kgs of wood fuel and 1147.2 Kgs of charcoal were saved annually by those households using biogas which translates into conservation of forest cover, and by extension, the preservation of forest benefits including carbon sinks. Taking into account the 200 households that were using biogas technology in the study area, approximately 303.8 metric tonnes of wood was saved annually from firewood and 229.4 metric tonnes from charcoal consumption. Perhaps this disclosure comprehended could serve as a major impetus for development agencies and environmentalists to increase their campaigns for accelerated uptake of the technology by many more households, and consequently see a point of departure from wood fuel.

4.3.4 Carbon Emissions Savings and Climate Change Abatement

Being one of the leading causes of deforestation, wood fuel consumption leads to increased emission of CO_2. Biogas technology has the potential to remarkably reduce emissions by reducing firewood consumption, and hence in conserving forests. In the study, an estimated net saving of about 1,519.2 Kgs of firewood annually was identified.

Bailis, 2003 and Smith *et al.*, 2000 gives emission co-efficient for firewood, charcoal, LPG and kerosene as 1536, 2411, 3085, and 2943 g/kg of dry fuel. Based on these emission factors therefore, a household using biogas energy helped mitigate approximately 2.333tonnes of CO^2 from being released into the atmosphere from firewood avoidance, 2.766 from charcoal and 277 kgs from LPG substitution with the biogas (Table 15).

Table 15: Net Fuel and CO^2 equivalent emissions reduction after installation of biogas

Fuel Type	Total Amount Used Before Installation	Total Amount Used after Installation	Net savings Monthly	Net savings Annually	Conversion Factors (g/kg of fuel) [a]	Total CO_2Eq Emissions Saved(tonnes)
Firewood in Kgs	187.5	60.8	126.6	1,519.2	1536	2.333
Charcoal	114.0	18.3	95.6	1,147.2	2411	2.766
Electricity (in KShs)	1746.9	1567.2	179.8	2,157.6		*
LPG (litres)	7.5	0.0	7.5	90	3085	0.2777
Kerosene (litres)	0.7	0.2	0.5	6	2943	0.0176
Total						**5.3943**

[a] Bailis, 2003; Smith and Uma *et al.*, 2000 *Electricity consumption was measured by proxy in terms of monthly bills

The observed 71.4% reduction in kerosene use helped mitigate about 17.6 Kgs CO_2eq from being emitted annually. Overall, upon acquisition and use of biogas technology by an average household, helped saved approximately 5. 4 tonnes of CO_2 from being emitted to the atmosphere. It can be argued therefore that the 200 households studied helped avoid approximately 1,078,900 Kgs CO_2eq from being emitted into to the atmosphere annually, which is an enormous way of mitigating global warming.

Shrestha *et al.* (2003) found that biogas plants of sizes 4, 6 and 8 m^3 mitigated about 3, 4 and 5 tonnes of carbon dioxide per plant annually. According to Winrock and Eco Securities (2004), the available carbon reduction per year per plant from the displacement of wood fuel, agricultural residues, dung and kerosene was approximately 4.6 tonnes of carbon equivalent. Biogas plant sized 6 m^3 displaced the use of 3 tonnes of wood fuel and 38 litres of kerosene annually, and reduced 4.9 tonnes of carbon dioxide equivalent per year (Devkota 2007).

Yu *et al.*, 2008, estimated the environmental benefits of the digesters in China by determining GHGs reduction. Their study revealed a reduction of 45.59 $x10^6$ tonnes of CO^2eq per annum between 1991 and 2005 in rural China.

4.4 Biogas and Rural Livelihoods

4.4.1 Benefits and Impacts on Rural Livelihoods

The underlying hypothesis was that adoption and use of biogas energy technology lead to improved household health, income and time savings. Specific impacts of biogas energy on livelihoods of users' were investigated, in addition to other local, national and global benefits. Direct and indirect benefits to households and the environment were openly evident from the interactions with farmers during field visits, observations and from the data collected. Some of the most conspicuous benefits included; monetary and time savings, health advantage, increased community productivity, in addition to provision of clean, affordable and available fuel.

In order to capture a wide range of possible impacts, a Sustainable Livelihood Framework (SLF) model was used in the research design and also in data analysis. The model drew on the Sustainable Livelihood Approach (SLA) designed for the UK department for International Development (DFID), 1999, as a framework for assessing community assets. The following tangible benefits were revealed.

4.4.2 Financial savings

Significant monetary savings were realized by adopting biogas. While no tangible income from the use of biogas was reported, financial savings were evident on fuel expenditure (Table 16). For instance, biogas households spent on average KShs 1,882 monthly on LPG before biogas installation, and no expenditure at all after the installation. This was statistically significant (P=0.001), translating into 100 percent savings of KShs 1,882. Monthly expenditure on firewood and charcoal reduced from KShs 1,207 and KShs 1,204 before biogas installation, to KShs 377 and KShs 202 after the installation respectively, marking 72.1% and 82.2% reduction respectively. A net savings of about KShs 830 on firewood and KShs 1,000 on charcoal were recorded monthly.

On kerosene, there was notable savings of KShs 31 a month, which was statistically significant (P=0.003). With electricity, expenses dropped with a small margin after biogas installation. However, the net reduction of 180 KShs monthly was statistically significant

Table 16: Household expenditure on firewood, charcoal and other fuels before and after biogas installation

Fuel Type	**Average Monthly Expenditure on fuel before installation of Biogas (KShs)**	**Std Deviation**	**Average Monthly Expenditure on Fuel After Installation of Biogas (KShs)**	**Std Deviation**	**Mean difference**	**t**	**Sig. (2-tailed)**
Firewood	1207.1	933.0	376.5	508.02	830.67	15.27	0.001
Charcoal	1203.6	815.0	202.3	340.71	1001.3	19.38	0.001
Electricity	1746.9	1322.1	1567.2	1141.1	179.8	3.782	0.001
LPG	1182.2	1168.8	0.0	0.44	1182.1	13.76	0.001
Kerosene	46.2	11.61	14.8	4.66	31.4	3.017	0.003

Generally then, if an average household was using all the fuels; firewood, charcoal, electricity, LPG and Kerosene before the onset of the technology, and makes a shift to biogas energy, a total monthly saving of KShs 3,223 would be made. This translates to estimated savings of KShs 38, 676 (455 USD) per annum per household, and this is quite huge in terms of the net worth. With the monies saved, farmers narrated that they were able to meet other households' needs, among them being able to pay school fee for their children, construct better houses, buy food and make investment. Case study 1 brings out the detailed impact of biogas technology on households.

Case Study 1

Josphat Kori, a biogas farmer, lives in Ting'ang'a Location, *Ndumberi, Kiambu County. He is 60 years old, married to a primary school teacher and a father of two girls. He owns one and a half acres pieces of land, and the main crops are Napier grass, maize, beans and bananas. He has eight mature cows, six calves, three goats and eight chicken. He and his family resides in a permanent house made of masonry bricks. The household also owns a television set (TV) and a car. Farming is the main source of income to Koris household, with an income of approximately KShs 100,000 monthly mainly from dairy (sale of milk), supplemented by Mrs. Kori salary.*

Mr. Kori constructed his biogas digester back in the year 2000, having heard about the technology from a neighborhood dairy society where he is a member. His main motivation for installing biogas was to cut on huge firewood cost he was previously incurring. "I would use more than ten backloads of firewood in a month, just to warm water to use while milking. This was too much and costed me roughly KShs 1,500 a month" said Mr. Kori. His digester, a floating drum measuring 12 cubic meters was constructed by a private artisan, and the total installation cost was KShs 99,600. The following breakdown of the total cost was given; Construction stones (KShs 16,000), 20 packets of cement (KShs 14,000), hardcore (KShs 1,200), ballast (KShs 2,400), 6 heavy duty metal sheets at 3,000 per sheet (KShs 18,000), gas pipes (KShs 3,000), burner (KShs 5,000) and labour (KShs 40,000). However, the excited farmer did not seem to regret the relatively high installation costs. He said that the cumulative benefits accruing out of the digester far outweighs the cost. No additional cost is incurred, only for maintenance and labour, which are negligible and provided by the household. The farmer had not experienced any mechanical problem or leakage with his digester, and therefore no maintenance cost had been incurred. The main substrate used in gas production was cow dung. He uses 6 to 10 buckets of dung weekly.

The main feeds to Koris' cattle include Napier *grass and brewery-by product locally known as 'machicha'. In a week, he uses two pick-ups load of Napier grass, which he buys at KShs 3,000 per pickup totaling KShs 6,000. Mr. Kori also buys ten units of Machicha at 5,700 KShs and animal salt lick for KShs 3,000. The household obtains water from a shallow well within the farm. On average, in a month, Mr. Kori uses about KShs 58,000 on livestock feed. He is able to sustain this from sale of milk, which fetches quite a lot. In a typical day, the farmer milks 100 litres of milk from five cows, with one litre retailing at KShs 35. This translates into an income of KShs 1,750 daily and KShs 52,500 monthly on average. When all the eight cows are yielding, the farmer can make up to about KShs 100,000 in a single month.*

With a lot of passion, Mr. Kori narrated that since he started using biogas energy, firewood consumption had reduced tremendously, and so was the expenditure. Before he installed biogas, the now happy farmer used to buy 10

> *backloads of firewood at KShs 1,500 and one bag of charcoal at KShs 500, and this would last one month. He would also consume electricity equivalent to KShs 1,500 and 13 Kgs capacity LPG costing KShs 1,500. On average, the total expenditure on fuel alone would be roughly KShs 5,000 in a month. Additionally, Mr. Kori would spend approximately 2 hours monthly to purchase these fuels. The situation changed drastically with the coming of biogas, and the household does not consume firewood anymore. "My household cooking needs are well catered for by the biogas" the farmer asserted. Nonetheless, he still consumes electricity for lighting and heating bathing water, and this costs him on average KShs 2,000 a month. Mr. Kori was quick to note that the higher cost of electricity was probably the result of inflation. Occasionally the family uses charcoal (for instance when doing barbecues), and a bag of charcoal now lasts three months at a cost of about KShs 800.The household also uses LPG (especially during cold days when biogas yield is low), with the 13kilos cylinder lasting 2 months compared to one month pre-biogas. On average, Mr. Kori now pays about KShs 3,520. "I am able to save about KShs 1,480 every month on fuel, and all this is due to the biogas. Of importance too, I also save a lot of time otherwise used on firewood gathering, and I am able to use that time in my dairy farming and also with my family. Our cooking has also changed, and we now cook from the main house, since the fire does not produce smoke and or blacken our utensils. With the financial savings on fuel, Mr. Kori is able to supplement his 2 children's tertiary education at Utalii College where he pays KShs 120,000 annually for each child.*
>
> *Use of bio-slurry on the farm was another benefit. Before the use of biogas, he was using raw cow manure and he could harvest on average 90 Kgs of maize compared to 210 Kgs when he started using bio-slurry.*

4.4.3 Time savings and Workload reduction

Considerable time was saved by households, after biogas installation since the need to go out to collect/purchase firewood and other fuels like charcoal declined significantly. Cooking and heating also became less time consuming and less cumbersome with the biogas stove. An overwhelming 95% of respondents said they were now using less time on collecting firewood, while only 3% mentioned to be spending more time. Majority of biogas users (56%) reported saving roughly 1-5 hours weekly. Worth noting is that purchasing firewood from vendors consumed more time compared to collecting from forests and private land. Table 19 shows the amount of time spent on sourcing firewood from the three sources; forest, private land and vendors, before and after biogas installation.

Table 17: Household time savings before and after biogas installation

Time spent in sourcing from	**Time spent in sourcing fire wood before biogas installation (hours)**	**Std. Deviation**	**Time spent in sourcing fire wood after biogas installation (hours)**	**Std. Deviation**	**Mean difference**	**t**	**Sig. (2-tailed)**
Forest (*N=179)*	0.7	1.6	0.2	0.7	.50	5.2	0.001
Private land *(N=171*)	0.5	0.97	0.1	0.6	.40	5.6	0.027
Purchasing *(N=177)*	1.6	1.15	0.6	0.8	1.01	12.4	0.001

Statistical analysis indicates that the time saved in firewood sourcing irrespective of the source was highly significant at P=0.001 (Table 17). This results into huge workload reduction and allocation of more time into productive uses within the households.

Less time was used for cooking with biogas. This was a major observation by women respondents during interviews and case studies. Their estimated time savings were more or less one hour per day. The reduced time in cooking was probably because lighting the fire was less cumbersome, and they did not have to attend the fire all the time. Also the biogas cookers could be used instantly, as opposed to firewood that takes time to prepare and ignite, especially during rainy seasons when wood is wet. In a study by Zohava (2011), in Son La Vietnam, time savings was observed only to those who used to collect and use firewood in the past. Similar findings and sentiments were expressed in a study by CMS (2008), which showed time savings of 93.2 minutes per day by households using biogas. Studies carried out by SNV (2009) in Bangladesh shows that 48.6 minutes per day of cooking time was saved by using biogas and, because of this, women were able to engage in income generating activities, and gave increased attention to their children enrolment in school. The time saved also provided greater opportunity in social work. None of the respondents, who used to cook solely on LPG previously, reported time savings after shifting to biogas.

Based on the Sustainable Livelihood Approach (SLA), the extent to which time saved is an asset crucially depends however on the returns to time in alternative uses. More than 80% used the time saved mainly on farming and tending their livestock. About 56% of the respondents reported that they were now able to spend more time with their families, and this helped strengthen family relations and networks. Another 20% respondents reported that they used the time to work for pay and this helped enhance their incomes. About 17.4% used the time saved to fetch water, which helped to improve household hygiene and nutrition. Of most importance, 7.4 % of the respondents reported that their children were relieved of firewood collection task, and were therefore able to attend school, get an education and a bright future. This is especially true to the girl child who are mostly involved in firewood gathering.

As observed in the energy ladder, when people do not have access to modern energy, they are undermined in productive undertakings and in their efforts to raise their living standards (Barnes and Floor, 1996). Two obstacles to such efforts are the loss of time, and money, associated with reliance on traditional fuels. Less time is available for productive activities if wood fuel must be collected. Consequently, adoption of the technology led to increased labour productivity, enabled households to engage in new production activities, and yielded a more beneficial allocation of household time, depending on opportunities, needs and preferences.

4.4.4 Health Benefits

Cooking with firewood, dung and crop residues is associated with significantly higher health risks due to indoor air pollution. When respondents were asked to give an approximation on the levels of smoke produced when using biogas in comparison with wood fuel, 99% of the respondents reported that the amount of smoke produced when using firewood and charcoal was much more compared to biogas, and only 1% reported that smoke levels were the same irrespective of the fuel type in use. When asked if they experienced dizziness or (and) headache when cooking with firewood and charcoal, 70.4 % responded in the affirmative while 27 reported that they did not experience the symptoms. When the same question was posed on their experience with biogas stoves, majority (95%) of the respondents reported that they did not experience dizziness or headache when using biogas and only a few of the respondents (4%) reported in the affirmative

A further investigation on the incidences of coughing and itchy eyes among users when cooking with the traditional fires compared to biogas stove, revealed that 70% of the respondents experienced cases of coughing and itchy eyes while using firewood and charcoal. When asked their experience with biogas cookers, only 8 % said they experienced coughing, while an overwhelming majority of respondents (92 %) did not cough or rub their eyes when using the new devices (biogas cookers). Figure 10 shows health effects among household members disaggregated by gender, before and after biogas installation. Case No. 2 brings out the health impacts to households, in addition to the other benefits.

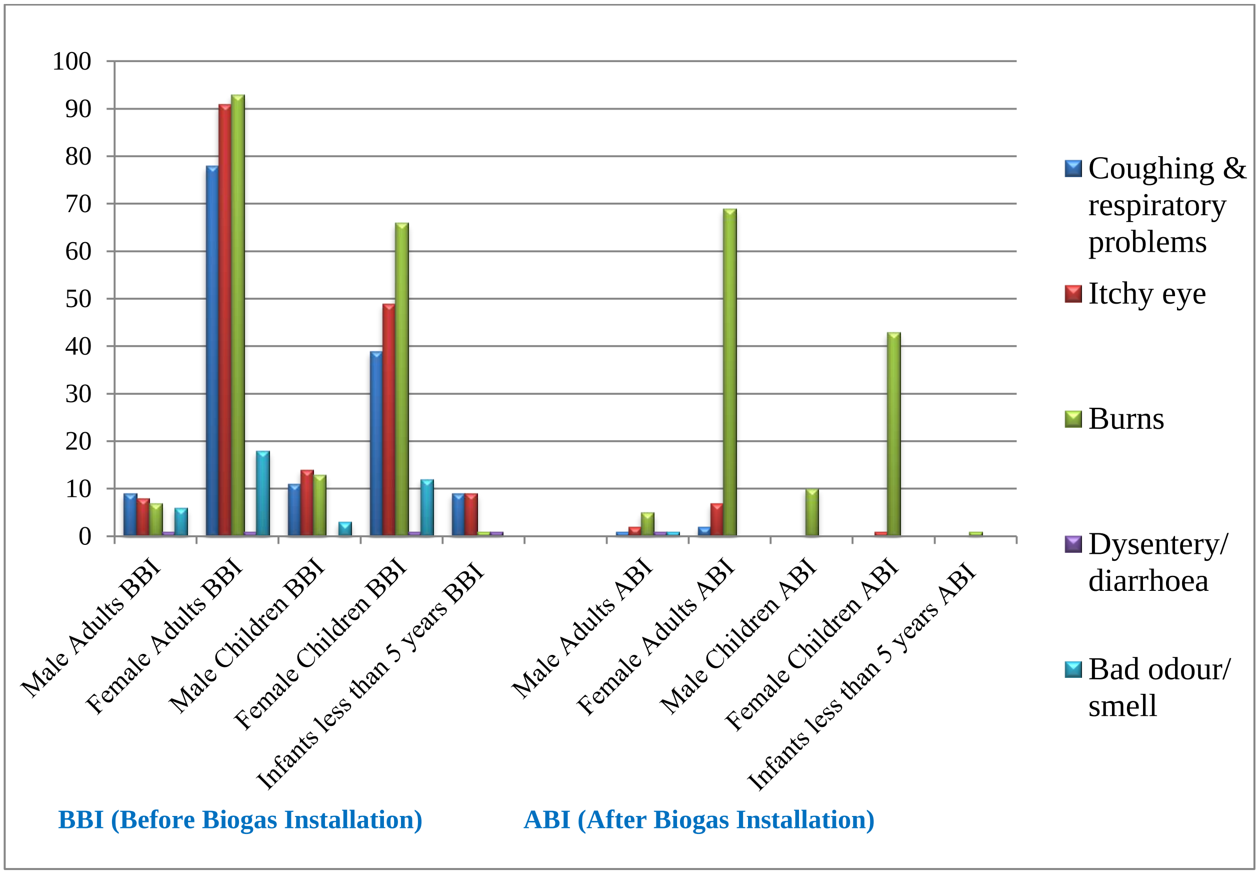


Figure 10: Health effects before and after installation and use of biogas

It is worth noting that physical burns, itchy eyes and respiratory problems were the most cases by gender and age bracket of the family members. Female adults (25 years and above) and female children were the most affected. For example, during pre-installation phase where the household would depend on firewood and charcoal for cooking, 53.4 %

female adults and 27 % female children reported coughing and other respiratory ailments while only 6.2 % male adults and 7.5 % male children had similar problems. The number of cases reported dropped significantly with the use of biogas, where only less than 3% female and male adults reported experiencing respiratory problems. This reduction is mainly attributed to biogas fire, which is clean and produces no smoke, is pollution free and with no particulate matter and therefore likely to cause minimal or none at all health harm to users (Carolyn *et al.*, 2012).

The high number of females both adults and children affected by smoke compared to their male counterparts could be explained by the fact that in most African cultures, women are the ones who are involved in food preparation for the household, and therefore spend most of their time in kitchens (which are often poorly ventilated), and hence become more exposed to products of incomplete combustion (Kammen *et al.*, 2007). There we no girls who had respiratory related problems on post-installation, and this could perhaps be attributed to the fact that girls could go to school since their need for collecting firewood and helping mothers with household chores had been reduced significantly.

Other health issues identified included burns, bad odour and dysentery. These too were reported to be widespread pre-installation phase of the biogas, but reduced tremendously with biogas use. For example about 51.7 % females reported that they had burns pre-installation period compared to only 4 % post installation. This drop in burns could be attributed to a reduction in firewood use and hence less burns resulting from physical pushing of the burning pieces of wood.

The findings of this study agree with the findings by Harikatuwal and Bohara (2009), on impacts of biogas on rural households in Nepal. They reported that disease incidences dropped drastically post biogas installation, with females reporting the most decline. For example; among females, there was 39.7% reduction in eye infections, 40.9% in headaches and 26% in cough and respiratory ailments. Similarly, men in the same population reported 19.7% reduction in eye infections, 20.2% in headaches followed by 15.3% in cough and respiratory problems.

In the current study, the observed decline in health related problems with biogas use, was attributed to reduction in user exposure to products of incomplete combustion (PIC) such as CO, nitrogen dioxide (NO_2), polyaromatic hydrocarbons (PAHs) and elemental carbon aggregates (soot), resulting from residential wood combustion. Use of firewood and charcoal produces obnoxious smoke and particulates (Bruce *et al.,* 2000), which could have posed direct health risks and respiratory diseases such as acute lower respiratory infection, reported as coughing. Exposure to ambient particulate matter has been associated with a range of negative health effects including increased morbidity and mortality from pulmonary and cardiovascular diseases (Ostro *et al.,* 2006). Borm and Donaldson, (2007), and Barregard *et al.,* (2008) in their studies associate particulate matter from wood combustion with a range of pulmonary effects such as decreased lung development and function, exacerbation of asthma, chronic obstructive pulmonary disease (COPD) and increased incidences of lung cancer. Several mechanisms including particle induced oxidative stress, inflammation, cyto-toxicity and genotoxicity have been used to explain the association between particle exposure and adverse health effects. Burning wood of poor quality (e.g. with high moisture content), overloading the fireplace and insufficient air supplies are examples of conditions that can lead to incomplete combustion.

According to Integrated Environmental Impact Analysis carried out by Biogas Support Programme in Nepal on 600 biogas users and 600 non-users, 4% more non-biogas users had respiratory diseases compared to those that were using biogas energy (BSP, 2000). Quantitative information from various household surveys revealed that problems like respiratory illnesses, eye infection and lung problems decreased after installation of biogas plants (BSP, 2000). Mwakaje (2008) observes that by substantially reducing indoor smoke and drudgery for women biogas digesters contributes to improved health and reduction in medical expenditure. This observation is also reported by Srinivasan (2008).

4.4.5 Impacts on Sanitation

Bad odour around homesteads was reported during pre-installation phase only. The absence of foul odour could be attributed to the clean environment that comes with biogas use. Using cattle dung in gas production prevents its accumulation in heaps, which would otherwise yield ammonia (NH_3) gas, with its characteristic pungent smell. This finding is collaborated by an observation that cow pens were especially clean in biogas households compared to non-biogas households. Moreover, the biogas produced is adourless, compared to wood and charcoal combustion which produces obnoxious gases such as SO_2 and $NO_{2.}$ Some respondents also pointed out elimination of unpleasant smell of manure on crops and a reduction in the number of flies in the farm. Studies carried out in Uganda by Sendegeya and da Silva (2006) show that use of biogas cleans up the home environment. Biogas is comparatively clean and hygienic (Jingura and Matengaifa, 2008), probably because bacteria and other pathogens are destroyed through anaerobic treatment.

4.4.6 Bio-slurry and Improved Crop Yields

Most households produced between 10-100 litres (34%) and 101-1000 litres (48%) of bio-slurry in a week. About 89% of the respondents reported using all the bio-slurry on-farm, while 11% opted to sell or give out to neighbours who did not own cattle. Perhaps these farmers did not realize the potential of the slurry, and thus the reason for disposing it. There is need therefore to sensitize such farmers on the significance and potential of the bio-slurry as organic fertilizer.

Majority of the respondents who used the bio-slurry were satisfied with the results, saying that crop yield had improved tremendously compared to the use of raw manure. About 85% of the respondents reported that the crops yielded higher when bio-slurry was used, while 11% said the yield was the same and only 1% said that the bio-slurry was not as good as raw manure. Studies have found that one Kg digested dung (bio-slurry) can yield up to an extra 0.5 kg nitrogen compared to fresh manure (Sasse, 1988), and the N:P:K content is 27:1.9:2.2 respectively (CMS, 1996). On the other hand, farm yard manure is highly exposed to environmental factors, leading to nutrients loss by volatilization, and consequently fewer nutrients are available for crop use. Moreover, the process of methane production serves to narrow the carbon: nitrogen ratio (C/N), while a fraction of the organic nitrogen is mineralized to ammonium (NH_4^+), and nitrate (NO_3^-), which are immediately available to plants, resulting to improved fertility and crop yield. Mtambanengwe and Mapfumo (2005) and Fonte *et al,* (2009) argues that the productivity of soil can be improved through improved soil structure and water holding capacity achieved by organic amendments of digested material to the soil Food production can be improved by application to the soil of digested material containing readily available nutrients (Onwosi and Okereke, 2009).

It is thus evident that the biogas technology helped improve soil nutrients and hence productivity. Consequently, less chemical fertilizers used helped in safeguarding the environment from chemical pollution, and saving households of revenue.

Case Study No. 2

> *George Nduati is a male farmer in Kimende area, Lari division in Kiambu County. He is married with three children. Besides being a farmer, Nduati is a trained electrician but not on any formal employment. He is 45years old. He owns one acre piece of land, three cows, two chicken and a semi-permanent house where he resides with his family. Napier and banana are the main crops that Mr. Nduati grows. He earns approximately 40,000 KShs in a month from milk sales. Main cattle feed is Napier grass supplemented with purchased dairy meal, which costs him KShs 2,800. Average milk production is approximately 36litres in a day, and this translated to KShs 37,800 (USD 445) a month.*
>
> *Nduati owns a 4m*^{3} *floating drum type modified with a plastic tank. He constructed the digester in 2010 and the main motivation was to be able to save finances, time and effort. He learned about biogas from a neighbour who had earlier installed. The middle aged farmer fully financed his plant from own savings and the total cost was KShs 62,750, with the breakdown given as: masonry stones 6,000; sand 6,000; 5 bags cement 3,250; plastic tank 20,000; pipes 3,000; two burners 2,500 and labour 22,000. Besides the construction/installation cost, no other costs had been incurred, but for labour, which is provided readily by the household members. Mr. Nduati expressed satisfaction with his plant since it requires very minimal labour and attention. He feeds dung only once in a week gas production is normally sufficient and sometimes produces in excess.*
>
> *Mr. Nduati has experienced massive financial savings arising from firewood and charcoal consumption reduction. For instance, before installation, his household could use firewood worth KShs 2,500 every other month, one bag of charcoal equivalent to KShs 400, and KShs 200 on five litres of kerosene.*

Additionally, the household used to spend 3 hours monthly collecting the firewood from vendors. With the installation of the digester, the farmer says that his household does not use firewood and charcoal any more. All his household energy needs are met by the biogas including heating water and boiling foods that take long to cook. He is therefore able to save on average KShs 36,000 (USD 420) annually, not to mention the time saved. Other benefits that the farmer cited, agreed to those of case study 1, and they included; absence of smoke in the kitchen which keeps pots clean, and a reduction in coughs and burns when cooking. Mr. Nduati also narrated that the gas is not explosive like in LPG and therefore minimal risks of fire accidents. "I also use the slurry on the Napier grass, and it does very well. I therefore do not have to use artificial fertilizers, which besides being expensive, damages the soils" said Nduati.

Mr. Nduati says that his immediate and future plans is to improvise on how he can fabricate cylinders to store the surplus gas produced for use during cold seasons. He also intends to sell to neighbours who do not own biogas digesters. The current challenge facing the farmer is how to compress and store the gas!

4.5 Biogas Production and Yield

Methane is the main component of biogas (50-70%), and it is the one that burns to give energy (Odeyemi, 2001). Other components include CO_2 and traces of H_2S. The working hypothesis was that cattle feed with high nitrogen content leads to production of high methane concentration in the gas relative to carbon dioxide, thus improving on the quality of the gas. Nine feed combinations were used to test this assumption. Feeds were a combination of two or more feeds common among dairy farmers and all had Napier grass as the sole feed, combined with either maize stover, dry grass, fodder legumes, sorghum and barley wastes, chicken droppings, commercial feed concentrates (dairy meal, and pig meal), silage, molasses and brewers' grains (a by-product of beer production). Different animal diet yielded varying content of CH_4, CO_2, and H_2S gases, and consequently impacted differently on gas quality.

4.5.1 Effect of Digester Type and Size on Methane yield (%CH_4)

Across the three digester types studied; fixed dome, floating drum and tubular, methane content seemed higher under the fixed dome, though the difference with the floating drum was negligible. Very little data was available under tubular type due to its scarcity among farmers, and hence it was not studied in great depth. Mean percent methane was slightly high under the fixed dome (62.8%), with the floating drum yielding mean of 61.6%. When the variation across the various treatments was tested, methane content was relatively high for all the feeds under the fixed dome, except for Napier grass + maize stover, which yielded slightly higher 62.3% in floating drum compared to 62.1% under fixed dome (Table 18).

Table 18: Effects of cattle feed type, digester type and size on CH_4 content in biogas

Feed Type	**Digester Type**			**Digester Size**					
	Fixed dome	**Floating drum**	**Tubular**	**$4m^3$**	**$6m^3$**	**$8m^3$**	**$10m^3$**	**$12m^3$**	**$16m^3$**
Dairy meal	-	61.4^c	58.2^b	58.2^a	61.4^a	-	-	-	
Maize stover	62.1^c	62.3^b	-	-	-	62.7^c	-	-	62.4^a
Maize stover +Dairy meal	62.8^b	62.4^b	62.2^a	62.5^a	62.2^a	-	60.2^b	62.6a	61.9^a
Maize stover + Dairy meal +Chicken droppings	64.2^a	-	-	-	-	-	64.2^a	-	-
Maize stover + Dairy meal + Fodder legumes	63.8^a	63.4^a	-	-	-	63.5^b	-	63.7^b	$61.^b$
Silage + Dairy meal +Molasses	62.8^b	62.3^b	-	-	-	64.3^a	-	62.6^a	-
Maize stover + Barley + sorghum	59.3^d	-	-	-	-	-	-	-	59.3^c
Maize stover + Dairy meal + Brewers grains	61.9^c	60.9^c	-	-	61.5^a	60.1^d	-	-	62.2^a
Maize stover + Dairy meal + Pig feed	63.4^a	63.4^a	-	-	-	63.5^b	-	-	
Critical Value of t	1.9	2	3.2	4.3	2.4	2.0	3.2	2.1	2.1
LSD -	1.3	1.136	3.2	5.1	0.8	0.6	0.1	1.5	1.2
P Value	.0001	.0001	0.1	0.8	0.1	.0001	.0001	0.01	0.002

*% methane content

*Different letters in superscripts indicates that means down the columns are statistically significant

*All feed types had Napier grass as the primary feed

The fact that fixed dome digesters are made of concrete and installed underground where they are then covered with soil, could have lead to generation and retention of high temperatures, since the digester is well insulated, enabling mesophilic (35ºC to 40ºC), digestion and attainment of higher biogas production. On the contrary, the floating drum are made of metal and plastic drums, and installed in an open tank, and are therefore highly susceptible to temperature variations, based on the prevailing weather conditions, a condition which may not assure attainment and maintenance of high temperatures optimal for gas yield.

Gas production for sizes $4m^3$, $6m^3$, $8m^3$, $10m^3$, $12m^3$, and $16m^3$, were studied under the two digester types. There was no relationship either negative or positive between methane content and the digester size. To illustrate this for example, under $6m^{3,}$ $8m^{3,}$ and $16m^{3}_{,}$ mean CH_4 content was 61.7%, 63.2% and 61.6% respectively. This indicates that methane yield content was not influenced by the digester size but rather the intrinsic factors such as environmental factors at play within the digester, and or the characteristics of the substrate. Size of the digester could perhaps influence the quantity of gas yield obviously because a large digester volume would accommodate more feedstock, and therefore more gas production. Similarly, small digesters would only yield as much owing to the limited capacity for intake and mixing of the substrate. This resonates well with findings from group discussions, where farmers having small-sized digesters said gas was not always sufficient (especially for those with big families) compared to those who owned bigger digesters, whose gas production exceeded consumption and had to share with extended family members.

4.5.2 Effects of Cattle Feed on Methane Yield (% CH_4)

Cattle feeds seemed to significantly influence gas content, with those rich in protein yielding gases slightly higher in methane than those with high fibers and sugars. Standard methane percentage in biogas is given in the range of 55 - 65%. As shown in Table 19, feed fortified with chicken dropping yielded the highest methane content of 64.2%, though this was not significantly different (at P=0.05), from the feed combination that contained fodder legumes, which yielded 63.8% under fixed dome and 63.4% under the floating drum. A third feed which was supplemented with pig feed was also not statistically different in methane yield (63.4%). Napier grass, maize stover and dairy meal combined, was the most popular feed among farmers, and gave methane content of about 62%. This was significantly lower than methane gas by feed containing chicken dropping, fodder legumes and pig feed. Fodder legumes (*calliandra* and *desmodium*) have high content of crude proteins, which when metabolized increases the proportion of volatile solids (VS), resulting into markedly higher methane. Wieland, (2001) observes that cattle manure has a lower potential to produce biogas than pig and poultry manure, since most of the biodegradable carbon in cattle feed is already digested in the rumen and in the gut. Anaerobic digestion in the fore-stomach of ruminants is a major source of CH_4 emissions. Ruminants and pseudo-ruminants have large anaerobic fermentation chambers with more efficient digestion of carbohydrates, and degradation of plant cell walls. The microbial protein synthesized in the fore stomachs is then available for further digestion in the small intestines. This is not the case with non-ruminants such as poultry and pigs, and their manure is thus high in degradable content. This concurs with Hobson's (1981) findings that attributed low methane yield to low biodegradable material in the cow dung. However, Yeole and Ranande (1992) attributed the higher biogas yield from the chicken dropping to the presence of native micro flora, while Fulford (1988) attributed it to low C: N ratio.

A combination of Napier grass and maize stover yielded significantly higher methane (62.3%) content compared to a blend of Napier grass and dairy meal; 61.4%. The probable explanation for this is that fermentation of cell wall in the maize stover, Napier grass combination yielded higher acetic and propionic acids, leading to higher CH_4 yield (Beever *et al.,* 1989). Moe and Tyrell (1979), found that fermentation of soluble carbohydrates (such as those found in dairy meal feed concentrate) to be less methanogenic, than cell wall carbohydrates. The argument is contradicted by methane yield under molasses (a by-product of sugar processing), that yielded slightly higher CH_4 content (62.8%) than in Napier grass and maize stover. Molasses feed was combined with dairy meal and dry silage. Though with considerable levels of soluble sugars in molasses and virtually no proteins, the elevated methane levels could be due to presence of cell wall carbohydrates in the silage. Moreover, during the silaging process, lactic acid, acetic acid, methanol, alcohols, formic acid, H^+, and CO_2 could have formed. These products are important precursors for methane formation (Madigan *et al.,* 2001). Misi and Foster (2001) in their study found that digestion of cattle manure with molasses increased methane yield. Another reason for the increase in methane yield could be a pre-decomposition of crude fiber in the course of the silaging, which improves the availability of nutrients for the methanogenic metabolism. Miller (1995) reported that feed rich in crude fiber stimulated micro-organisms within the cellulolytic methanogen consortium, which serves to couple the degradation of carbohydrates with the use of H_2 to reduce CO_2 to methane.

Feeds containing brewers' grains (a by-product of beer production) gave CH_4 mean of 61.9% and 60.9% in fixed dome and floating drum respectively. This was significantly lower than in chicken dropping, pig feed and fodder legumes. Though brewers' grain is a high protein feed (all sugars having been squeezed out as malt leaving behind a concentrate of proteins, fiber and vitamins), CH_4 content could have been low possibly due to microbial growth of yeast and fungi, which might have inhibited methanogenesis. Usually, this feed (brewers' grains) is sold out to farmers in wet form, and this offers an excellent medium for microbial growth (Wyss, 1997; Wadhwa *et al.*, 1995). In addition, it is observed that the brewers grain though quite palatable, are less ruminally degradable due to high fiber content and amino acid lysine, which limits digestibility. This contradicts findings by Bonhomme (1990), who reported that brewers grain feeds are rich in soluble carbohydrates, increases the population of ciliate protozoa, stimulating hydrogen transfer to methanogens, resulting in high methane production.

Barley and sorghum wastes reduced the effect of Napier and maize stover combined yielding mean CH_4 content of 59.3%, which was relatively low. Although sorghum is highly proteinous, its grain pericarp contains tannins which decreases its food value and organoleptic qualities (Lazaro *et al.,* 2000). High lignin content too (more than 25% DM) reduces the digestibility of sorghum grains (Cavani *et al.,* 1990). Chandler *et al.*, (1980) found several relationships between substrate composition and substrate biodegradability. Structural substances, especially lignin are key organic substrates in biogas plants (Amon *et al.*, 2002a; Scherer, 2002). Methane production depends on their composition and the content that can be biodegraded to CH_4 and CO_2.. MacDonald and McBride, (2010), asserts that the ultimate yield of biogas depends on the composition and biodegradability of the organic feedstock. Crude protein, crude fat, crude fiber, cellulose, starch and sugars markedly influences CH_4 formation (Amon *et al.,* 2002b; 2004a). Sorghum and barley waste are also thought to be high in crude protein, which is degraded to NH_4, and in turn the ammonium combines with CO_2 to form $(NH_4)HCO_3$ (Getachew *et al.,* 1998). Since CO_2 is a substrate for methane formation, its combination with NH_4 inhibits methanogenesis resulting into low CH_4 yield.

Mshandet *et al.,* 2004; and Parawira *et al.,* 2004, observed that co-digestion of different materials enhances the anaerobic digestion process due to better carbon and nutrient content. The amount of methane generated depends on the quantity of volatile solids. In other words, the amount of solids present in the waste, and their digestibility or degradability (Sarba, 1999).

4.5.3 Effect of Cattle Feed on Carbon Dioxide Yield

Feed containing chicken dropping yielded the least CO_2 (34.9%), which was significantly different ($P<.0001$) from other feed types (Table 21). Barley and sorghum feed gave the highest carbon dioxide, (40.2%). Feeds containing fodder legumes, molasses and pig feed yielded 37.9%, 35.2% and 35.7% of CO_2 respectively. The variation in CO_2 between the feeds was statistically significant.

With regard to the best gas quality (high methane and low carbon content), supplementing forage feeds with chicken dropping ranked top since it gave gas with the highest content of methane (64.2%), while at the same time yielding gas with the least CO_2 (34.9%). Maize stover combined with barley and sorghum was the least attractive. It produced gas with the lowest methane content of 59.3% and the highest CO_2 content of 40.2%. This feed combination would be the best for cattle management regime for biogas non-adopting dairy farmers, since it would have the least enteric methane emissions, and therefore less environmental harm. For farmers who had adopted biogas farmers, low methane levels resulting from this feed type management, would not be cost-effective due to low calorific energy yield.

The presence of high CO_2 in biogas is unsatisfactory for a number of reasons. It lowers the power out in terms of the calorific value of energy, takes up space in the storage cylinders, and can cause problems of freezing at valves and metering points, as well as problems with compression and storage procedures. Furthermore, CO_2 is a major green house gas. Biogas produced should therefore have minimal levels of CO_2 possible.

Table 19**:** Effects of cattle feed type on CO_2 content in biogas

Feed Type	**Digester Type**			**Digester Size**					
	Fixed dome	**Floating drum**	**Tubular**	**4m3**	**6m3**	**8m3**	**10m3**	**12m3**	**16m3**
Dairy meal	-	37.4^{a}	41.1^{a}	41.1^{a}	37.4^{a}	-	-	-	-
Maize stover	35.8^{d}	37^{b}	-	-	-	36.2^{b}	-	-	37.1^{c}
Maize stover +Dairy meal	36.3^{c}	38.4^{a}	37.2^{b}	41.2^{a}	37.1^{a}	-	38.3^{a}	36.6^{b}	37.1^{c}
Maize stover + Dairy meal +Chicken droppings	34.9^{e}	-	-	-	-	-	34.9^{b}	-	-
Maize stover + Dairy meal + Fodder legumes	37.9^{b}	37.9^{a}	-	-	-	35.8^{b}	-	39.4^{a}	38.5^{b}
Silage + Dairy meal +Molasses	35.2^{d}	35.3^{d}	-	-	-	34.9^{c}	-	36.2^{b}	-
Maize stover + Barley + sorghum	40.2^{a}	-	-	-	-	-	-	-	40.2^{a}
Maize stover + Dairy meal + Brewers grains	36.9^{c}	38.2^{a}	-	-	37.7^{a}	38.9^{a}	-	-	36.9^{c}
Maize stover + Dairy meal + Pig feed	35.7^{d}	35.7^{c}	-	-		35.5^{b}	-	-	-
Critical Value of t	1.9	2.0	3.2	4.3	2.6	2.0	3.2	2.1	2.1
LSD -	1.31	1.3	3.2	5.1	0.9	0.7	0.1	1.5	1.2
P Value	<.0001	<0.001	0.13	0.8	0.14	.0001	<.0001	0.01	0.001
Error Mean Square	1.55	1.6	2.0	2.4	0.3	0.6	0.001	2.2	0.8
Mean Per Cent	36.3	37.5	39.1	41.1	37.5	35.9	36.6	37.5	37.6

*****Percent CO_2 content

*Different letters in superscripts indicates that means down the columns are statistically significant

*All feed types had Napier grass as the primary feed

4.5.4 Effect of Feed on Production of Impurities: Hydrogen Sulphide

There was no evident trend on H_2S yield with the type of the digester (Figure 11). For instance, brewers' grains yielded 91 parts per million (ppm) H_2S under the floating drum and only 31 ppm under the fixed dome, while feed containing pig feed gave 86 ppm under the fixed dome and 34 ppm in floating drum. It can therefore be argued that the digester design did influence production of the sulphides. Feed containing brewers grains and pig feed, both rich in proteins yielded the most Hydrogen Sulphide (H_2S). Napier grass and Maize Stover combination yielded the least at 21 and 27 ppm. Fodder legumes did not seem to yield as much sulphide (though also high in protein) like counterpart proteinous feed that were observed to give high methane content.

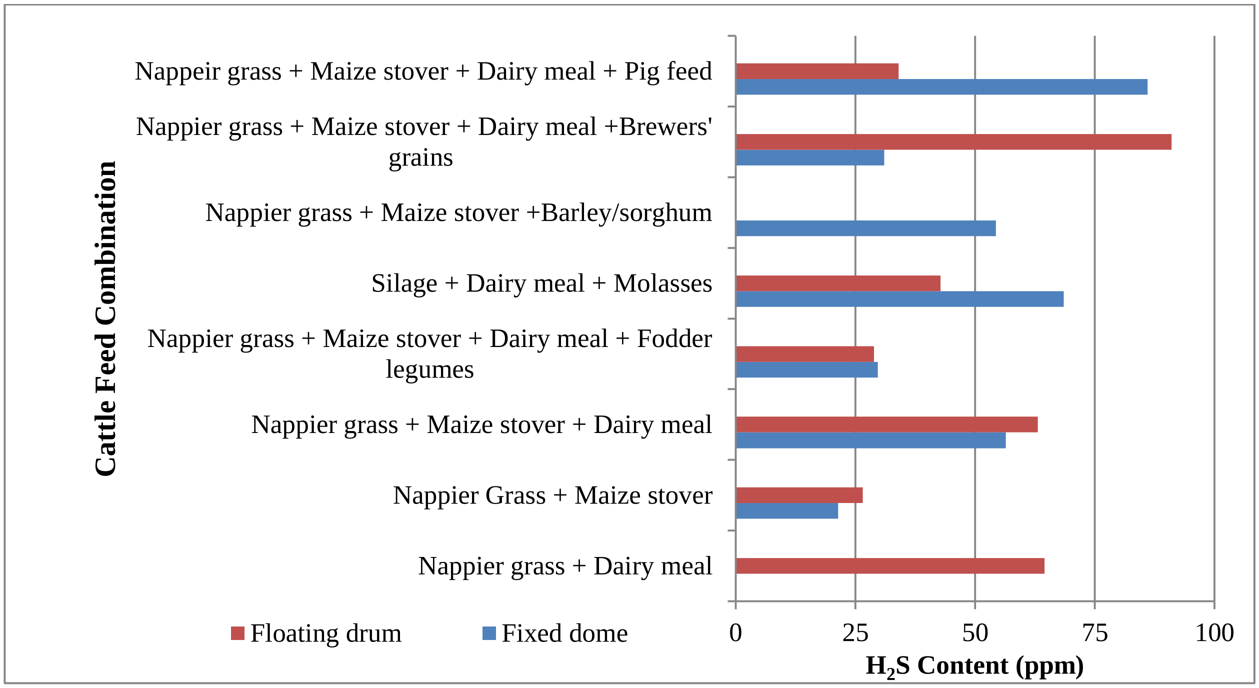


Figure 11: Levels of H_2S in biogas by various feed types (in ppm)

The best producing methane feed types, seemed to be the highest producers of the hydrogen sulphides. This is counteractive, since H_2S is a major pollutant with highly poisonous and corrosive properties. It forms explosive mixture with oxygen, and has a characteristic smell of rotten eggs. A combustion product is H_2S is SO_2 which gets very corrosive in sulphuric acid form, and contaminates the environment as acid rain. H_2S is comparable to hydrogen cyanide in toxicity. At 1.2 - 2.8mg H_2S per litre of air (0.117 %), it kills instantly, and at 0.6mg H_2S per litre of air (0.05 %), kills within 30 minutes to an hour. H_2S changes red blood pigmentation from red to brown when inhaled, and hinders oxygen transport, suffocating the patient internally. Its poisoning leads to cyanosis and cardiac arrest. Survivors of the poisoning suffers from long term central nervous system (CNS) damage.

The high levels of hydrogen sulphide yielded in the best producing methane feed combination, possibly resulted from the transformation of sulphur containing proteins in brewers grains and pig feed. It was also possible that the dung used contained bacteria, excreted in the intestines, and probably became a major source of sulphides in the biogas. Proteins rich waste can produce large amounts of H_2S. Napier grass and maize stover, which are less in proteins, yielded the least H_2S.

The high levels of sulphide in biogas is thus of concern, especially to indoor air health, and also as an environmental pollutant. It does also corrode pipes and the biogas plant system. There is need therefore to devise mechanisms for removing the sulphides from the biogas (desulphurization). Ferrous substances have been fronted as possible desulphurizers, an example being Iron (Fe) containing soils. Research into the feasibility of using Iron rich soils to remove the sulphides is thus needed.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This section highlights the most significant findings that the research has been able to establish. These are presented chronologically in the order of the four specific study objectives. Conclusions are drawn, recommendations stated and where necessary action points for further research specified.

5.2 Summary and Conclusions

Farmers in the peri-urban and rural Kiambu County own basically three types (designs) of biogas plants; the fixed dome the floating drum and the plastic tubular. These different types are fronted by different companies and agencies, and branded differently for identification purposes. The fixed dome was the most prevalent among the adopting farmers. The plastic tubular design though fronted as low-cost type, was very rare and in most cases not functional. The digesters came in different sizes ranging from $4m^3$ to $32m^3$, and this depended on several factors, among them being; the number of cattle, space/land availability and the initial construction cost.

Biogas energy was found to be a very fundamental resource to the adopter households. Its main applications mainly were cooking, lighting and in a few cases driving light machines. However, the technology adoption level in the County was quite low. Out of the 469,244 households existing, it is only about 200 households who had taken up the technology. Many factors were found to be responsible for the low adoption levels.

There was a high likelihood that a combination of the independent variables; size of farm, age, education level, type of house and number of cattle owned, led to adoption of the technology by a household. The larger the size of the farmed owned by the household, the more was the likelihood to adopt the technology. The herd size or the number of cattle owned was important too. A large herd led to a higher probability of adopting compared to households with fewer cattle. Gender of the household head, their marital status, family size and household income were not significant in biogas adoption. Nonetheless, the initial costs incurred in acquisition and set-up of such technology was considered a major barrier for technology diffusion.

The technology showed great potential and real benefits for uplifting the livelihoods of adopting households. Among these benefits included; financial savings, health benefits by way of reduced indoor smoke and clean home environments, time savings and social-economic benefits, which, overall helped to improve the welfare of adopting households. Biogas provided user households with clean, smoke free, locally available and instant energy, thereby eliminating or reducing the need for wood fuel, LPG and Kerosene. This helped the households achieve huge financial savings that would have otherwise been used to purchase the fuels. An average household using firewood, charcoal, electricity, LPG and Kerosene before the acquisition of the technology, was able to save a total of KShs 3,223 monthly upon shifting to biogas energy. This translates to estimated savings of KShs 38,676 (455 USD) annually per household, and this is quite huge in terms of the net worth. From the case studies and group discussions, the financial savings enabled households to take their children to school, bought more cattle for more milk production, purchased household goods and clothing, and importantly, purchased better food for the family. Others were able to cumulatively invest in physical assets overtime, and in business ventures, which overall helped enhance the welfare of the family.

Time savings after acquisition and use of biogas technology was another significant benefit to technology adopters, since the need to go out to collect/purchase firewood and other fuels like charcoal declined significantly. Cooking and heating also became less time consuming and less cumbersome with the biogas stove, as compared to the traditional fireplaces and charcoal stoves. Time saved and reduction of drudgery on women and children undoubtedly allowed for livelihood diversification, as a major outcome of technology adoption. Girls were now free to attend school and get an education, thereby improving on the human capital as a resource to the community, and also a strategy for livelihood advancement. The time saved became an important asset to the community, and this was invested in farming and dairy, fetching water, work for pay, and spending time with relatives which helped strengthen families' ties and networks.

Another major benefit that accrued from the technology adoption was an overall improvement in health of household members. Absolute reduction in amount of smoke in kitchens was reported. This saw respiratory ailments, eye cataracts and burns decline with a huge margin. Females, both women and children were the most beneficiaries of the improved indoor environments since they spend most of their time in kitchens, where preparation and cooking of food takes place. Other health benefits realized by technology adopting households was that there was improved sanitation around the home environment, reduction in foul odor and houseflies. Use of the bio-slurry for growing vegetables and other crops, led to better household nutrition, which might have improved the general health of the area residents.

Environmental benefits rendered directly or indirectly were numerous and included carbon sequestration, preservation of forests and a reduction in emissions of GHGs. Most remarkable was a reduction in firewood and charcoal consumption by adopting households, which meant that less trees and shrubs were cut.

Overall, it is noted that traditional fuels consumption reduced tremendously with the installation of biogas. Average firewood consumption per month per household was estimated at 187.5 Kgs and 60.8 Kgs before and after installation of biogas respectively. The study revealed a 67.6 % reduction in firewood and 83.95 % reduction in charcoal use, with acquisition and use of biogas. About 1519.2 Kgs of firewood and 1147.2 Kgs of charcoal were conserved annually. The technology also helped reduced consumption of LPG and kerosene by 100 and 71.4 % respectively. Taking into account the 200 households that were using biogas technology, roughly 303.8 metric tonnes of wood was conserved from firewood consumption and 229.4 metric tonnes from charcoal consumption annually. This consequently resulted into a more standing stock of trees in the woodlots or in the neighboring forests. In turn, environmental benefits such as amelioration of micro climate, soil and land preservation, carbon sequestration, preservation of biodiversity and attainment of non-timber forest products such as honey and herbal medicines, might have been achieved by the community.

On Carbon emissions reduction, and on climate change mitigation, a single household using biogas energy helped mitigate approximately 2.333tonnes of CO^2 from being released into the atmosphere from firewood avoidance, 2.766 tonnes CO^2 eq from charcoal and 277 kgs CO^2 eq from LPG avoidance. The 200 biogas farmers included in the study mitigated approximately 1,079 tonnes of CO_2 annually.

From a livelihood framework perspective therefore, biogas energy technology gave adopter households' essential assets that enabled the households achieve positive livelihood outcomes. Among the categories of assets, financial capital (from financial savings of up to KShs 38,676) was achieved, and probably was the most versatile since it could be converted into other types of capital, or used for direct purchase (achievement) of livelihood outcomes. Natural capital was also achieved in the sense that biogas helped improve air quality, preserve carbon sinks and forests products and services, and maintain the integrity of water resources through prevented erosion and eutrophication. These natural resources; clean air, healthy soils, forests, clean waters, are essential for the continued existence and general welfare of the community. Biogas technology also helped users to attain the physical resources of achieving a livelihood. These included the basic infrastructure that come with biogas plants; improved sanitation, better and clean housing, clean energy, and household items such as television, clothing, and farm implements. Biogas also helped in achievement of social capital through the networks and linkages created with biogas service providers and the wider community. About 20 % of respondents reported using up to 5 hours saved weekly to interact with relatives and friends. The social status (25.6 %) of user biogas adopting households was also elevated.

Overall, biogas was found to have a positive impact on the well being of user households. Because of the livelihood assets (financial, natural, physical, and social capitals), that user households were able to secure, their vulnerability to external shocks might have been rendered minimal. For instance, more secure fuel supply (biogas), improved food production due to use of the rich bio-slurry on farms, and enhanced education for children, all links back to the capacity of biogas users to cope with their external environment.

Type and size of the digester did not have a significant influence on the quality of gas in terms of CH_4 and CO_2 concentration. However and importantly, the quality of gas produced through anaerobic digestion was markedly influenced by type of cattle feeds. Different animal feed yielded varying methane (CH_4), carbon dioxide (CO_2), and hydrogen sulphide (H_2S) gases. The highest methane percent was achieved from chicken dropping, pig feed and fodder legumes used in combination with maize stover and Napier grass to feed the cattle. The lowest (poor quality gas) was obtained by feeding cattle with barley and sorghum wastes combined with maize stover and Napier grass. Feeding cattle with high protein feed, gave a combined optimal effect on CH_4 and CO_2 emissions. CO_2 is undesirable when in the biogas because, one, it lowers the quality of the gas, and secondly, it takes up space in the storage cylinders and challenges compression of the gas. In conclusion therefore, the study found out that different cattle feeds yielded varying levels of methane, and that biogas technology helped in recovering the methane gas into high energy fuel, before it would be emitted in the air, from the decomposition of cattle dung.

In conclusion therefore, biogas technology offered a myriad of benefits; social, health, economic, and environmental, and was a major driver of livelihoods in Kiambu County. Its role and potential in positively transforming livelihoods, in poverty alleviation and in environmental protection cannot be emphasized. Efforts are required to create an environment that promotes the adoption of this technology.

5.3 Recommendations

- Since the technology is huge in terms of the benefits, efforts should be heightened to see more households take up the technology. Full potential can only be realized if the population of biogas plants is brought to scale. In this regard, it is recommended that efforts be focused on: capacity building programmes for farmers, strengthening linkages between farmers, biogas fabricators and artisans, researchers, NGOs, donors, creditors and policy makers.
- The County Government of Kiambu should intervene by giving incentives such as subsidies to biogas construction materials, and (or) extending credit to farmers. This could go a long way in scaling up the technology, by making it more affordable.
- Given that the adoption process begins with complex interactions between users and the social-economic factors, it is necessary to understand these interactions from areas where it has been successfully adopted, and to create similar environments in areas where adoption is low. Exchange visits for non-adopter farmers to adopter farmers’ plants is recommended.

- Improving the overall wellbeing of households would go a long way in increasing biogas adoption levels. The more wealthy households, with highly educated household heads, and with more herds of cattle were able to adopt the technology. Programmes that improves households' finances and resources, would boost biogas technology adoption, and are recommended.
- Mechanisms and techniques for compressing and packaging biogas into tradable units should be devised. In addition, methods for transforming the gas into electrical energy for lighting and running machinery should be sought. This can earn users extra income, and at the same time avoid surplus gas wastage
- Integration of pig farming with dairy farming is especially beneficial to biogas users. Pig waste when used for gas production would raise the levels of CH_4 in the gas, and increase the calorific values in the fuel. However, this should be treated with caution since pig farming may increase the costs of running the farm to the farmer.
- Farmers are advised to supplement their cattle feed with chicken dropping especially since it is locally available and no extra cost is required. This will help elevate methane content and at the same time reduce CO_2 percent. Most farmers are advantaged since they have integrated poultry to their systems.
- Fodder legumes are also highly recommended. In addition to providing high quality gas, they would serve a handful of environmental benefits including absorption of the CO2 emissions resulting from biogas combustion

5.4 Areas for Further Research

- Studies are needed to quantify actual methane emissions reduction arising from biogas use. This is needed to be able to pursue trade in carbon credits, for adopter farmers, where they can benefit financially by having an added income. To this effect, baseline data on actual CH_4 emissions from the raw cow dung before biogas installation and use is needed. The mass of methane captured and burned is not the basis for calculating carbon credits. Instead, baseline emissions are used. The feasibility of carbon finance in biogas projects as clean development mechanism would be a very powerful strategy to enhance adoption in rural Kenya, where there is huge potential.
- Studies are also needed to investigate how bio-digester temperature, pressure and retention time, in combination with cattle feed regimes influences methane yield. This was a major gap in the current study, and a big shortcoming to the research. Farmers' set up was used, and the study did not have any control on the digestion process whatsoever. The digesters differed in the intricate details such as length and diameter of gas pipes and valves, amount of digestate and frequency of feed. There is need therefore to investigate these parameters and feed regimes in a more controlled manner, to see if there is any variation in gas yield with farmers' practice. Feed management and stage of harvests, feeding intensity to the cattle should be determined
- On biogas quality, research should be done on how to remove $CO_{2,}$ to enable compression of biogas into high pressure cylinders or other storage devices that can allow trade in the gas. Currently, farmers who produce sufficiently more

than they require do not have mechanisms for packaging and storing the gas. There is need therefore to explore mechanisms of scrubbing the gas off carbon dioxide, and how storage and packaging can be done in units that can sell in rural setting.

- Research is also needed to explore ways of improving biogas (raising methane up to 90%). This would enable its use in running of machinery and automobiles.
- Research is needed on the cost effectiveness of integrating pigs and poultry in dairy farming and also on the effects of different feeds, on milk production - the sole aim of dairy farming.
- H_2S is a major pollutant with highly poisonous and corrosive properties, and its presence in biogas is highly counteractive. The high levels of hydrogen sulphide yielded in the best producing methane feed combination, and ways of desulphurizing the gas before getting to the kitchens devised.
- Finally, research is needed to quantify nutrients content of bio-slurry and its actual effect as soil fertility amelioration product, and by cause-effect relationship, on food production.

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APPENDICES

Appendix 1: Checklist of questions used during case studies analysis of biogas success stories

Date

Area and location/division/district/village

Names of the respondent ………….Age of respondent …………………. Sex …………………….

Education level …………………….. Marital status…………………… Number of HH members ……

No. of cows ……………………….. … Farm size …………………………… House type……………….

Main crops ………………………………..

Any other assets…………………………….

Source of income……………………………. Approximate how much in a month…………………

Main occupation ……………………………..... Any other occupation………………………………….

Source of water……………………………………………………………………………………………….

Biogas Acquisition, Installation and use

Type……………………… ……….Size ……………………………..and number of bio-digesters

When did you install? How did you get to know about biogas? Who installed for you and how long did it take to install?

What do you use the energy for? Type of digestate………………………………………

How much money did it cost you to construct? Where did you get the funds from?

Does it cost money to maintain the biogas? If yes, approximately how much in a month?

What made you acquire the technology? (What reasons influenced your decision to install?)

What social, economic, financial and environmental benefits does the biogas give to you?

Any other benefits?

Life before the acquisition of biogas

How was life before you started using biogas?

What source of energy were you using for cooking, lighting etc?

Did you have any problem with these types of energy? *e.g. not available, smoke in kitchens, dirty, time, expensive, irregular supply,*

If firewood, approximately how much in a month (in kgs)?

How much time in a week was devoted to collecting firewood? What was the source?

How much money was used on firewood in a month?

Charcoal…….. LPG………. Kerosene………….. Electricity …………………..

Who mostly used to be involved in fuel gathering and collection?

Life after the acquisition of biogas

How is life generally after the installation of biogas?

Has your life and that of your family changed in any way? Please explain…………….

What do you use the biogas energy for?

How much gas do you produce? …………………. How many burning hours in a day.......................

Is it sufficient to meet your energy needs?..........................

What benefits have you obtained from using the gas? Time-wise, financial, socially, environmental, agriculture, children going to school, less smoky kitchens etc

How much money if any do you spend on biogas now?

What other sources of energy do you use apart from biogas?

Type (firewood), amount in a month, Time weekly, Money per month, source etc

Use of bio-slurry

How much bio-slurry do you produce weekly?

How do you use?

Does it have beneficial effects and how does it compare with shop fertilizers and manure?

Any increment in crop yield when you use?

Any other benefits that you would like to talk about?

In your own view, what is your opinion of biogas?

Have you heard about climate change? What do you think causes it? And what do you think is the contribution of biogas to climate change?

Appendix II: Questionnaire Set I (For Households with Biogas)

1. General Information:

Name of Respondent:.. HH Owner's Name: …………..............................

Age of Respondent: .... Family Size:............... Farm size (acres) ....…

Mobile phone of respondent (HH)……………...

Email of respondent (HH)……………………………………………….……..

Village Name: ………………… Sub-Location……………… Location………………

Household ID………………….Interview Date…………………Interview Time......................

Type of house: [1= Mostly earthen, 2 = Mostly wooden, 3= Mostly concrete

Do you have electricity [1 = Yes, 0= No]

Roof type: [1= Mostly grass roof, 2=Mostly iron sheets, 3=Mostly brick

Type of toilet 1=Flush 2= Traditional pit latrine 3= Ventilated improved latrine 4=Others (specify)

Is your toilet attached to your biogas plant [1 = Yes, 0= No]

2. Other Household Details

Question	Response (circle or enter)
Sex of the Household head	1. Male 2. Female
Age of Household head	………………………….
Marital status	1. Married 2. Single / Never married 3. Divorced / Separated 4. Widowed
What relationship do you have with the head of the household?	1. Wife 2. Husband 3. House Help 4. Daughter 5. Son 6. Other Relative (specify): ....
How many people live in your household and you cook for in a day	Enter number
How many children under 5 years old live in your household?	Enter number
What is your household’s main source of income?	1. Farming 2. Own Business 3. Employment (Corporate, Government) 4. Temporary employment 5. Unemployed 6. Other (specify): ....….

3. Characteristics of Household Members

Member name	Age	Education [0=none, 1= primary, 2=secondary 3=tertiary]	Main occupation *(see codes below)*	Approximate income/month [0=None 1= 0-50,000, 2= 50,001-100,000, 3= Over 100000	Gender 1= Male 2= Female	Months living at home (last 12 months)	Number of hours operating biogas plant in a day
Codes for main occupation and main source of income: 1. Farming 2. Own business/self employed, 3. Salaried Position (corporate, government), 4. Temporary Employment, 5. Unemployed, 6. Student, 7. Other (specify):							

4a. Information on Livestock Ownership

Livestock Type	**No. of animals**	**System of management** [1=Zero grazing, 2=Free range, 3=Tethering, 4=Semi Zero 5=Others…..]	**Types of feed** [1=Grasses, 2= Farm residues, 3= Fodder trees, 4= Napier grass, 5= Livestock feeds from shop 6= Kenya brewery residues (*machicha*), 7= Molasses, 8= Hay 9=Silage 10=Other	**Source of feed** 1= Own farm, 2= Purchased	**If purchased, give quantity (monthly)**		**Average monthly expenditure on feed (in KShs)**
					Qty	Unit	
Cattle							
Pig							
Goats							
Sheep							
Poultry							
Donkey							

Unit Codes							
1	90 kg bag	7	25 kg bag	13	Grams	19	Donkey load
2	Kgs	8	10 kg bag	14	wheelbarrow	20	Donkey cart load
3	Litre	9	Gorogoro	15	cart	21	Hand cart load
4	Crate	10	Tonnes	16	canter	22	Head load
5	Numbers	11	50 kg bag	17	pickup	23	Area in acres
6	Bunch (bananas)	12	Debe	18	2kg bag	24	Other (specify)

4b. Sales of livestock and livestock products:

Livestock Type	Quantity sold	Months mainly sold [1= January….., 12= December]	Distance to product market (km)	Value of products sold (KShs)
Cattle				
Pig				
Goats				
Sheep				
Poultry				
Donkey				
Milk (litres sold per day)				
Eggs (crates sold per week)				
Others				

5. Information on crop production

Main crops	Plot size per crop (acre)	Production (last season) (kg)	Consumption (kg)	Sold amount (kg)	Value of products sold (KShs)

6. General details on the Biogas Plant

Question	**Response (Tick or enter)**
Date of installation	
What type is your digester	1. AKUT 2. KENDBIP 3. CARMATEC 4. Other (specify)
What size is your digester (in cubic meters)	
Why this type and size of digester?	Give reason
How many biogas plants have you installed	
Name of the company that installed/ constructed your digester	
How many days did it take to complete the construction/ installation of the biogas plant	
Was the plant visited by technicians for supervision during installation	(1= Yes, 0= No)
What source of energy were you using before installation of biogas stove? ---	(1=Farm residues, 2= Dung, 3= Fire wood, 4=Charcoal, 5=Gas, 6=Solar, 7= Electrical, 8= Other (specify)
How did you learn about biogas technology? *(Tick: more than one choice is allowed)*	1= Government/NGO, 2 =TVs/Radio/ News papers, 3= Friend/neighbour, 4 = Exhibition/promotion, 5= Hardware/supermarket cages, 6= Other: (specify)
What material do you feed into your digester	1= Farm biomass, 2= Human waste, 3= Dung/manure, 4= Other (specify)…………
Are you currently using the biogas	1= Yes 0 = No
If No, why are you not using the biogas?	Give reason ……………………………………….
If Yes, what do you use the biogas for?	1= Cooking 2= Lighting 3= Light industries/Driving machines 4= Others (specify)
Dung production and use	
How much dung do you produce per week [in kg/debes/wheelbarrows]	
Is the dung sufficient for gas production? [1= Yes, 0= No]	
Do you use all dung you produce for gas production [1= Yes, 0= No]	
If not, how do you use the extra dung? [1= For farming, 2= For sale,3= No use, 4= other specify]	

Do you purchase dung for use in biogas production [1= Yes, 0= No]	
What quantity of dung do you buy per month (kg)	
How much money do you spend (KShs)	

6a) Purchase/Installation Decision and User Satisfaction

Why did you buy and install the biogas? (answers can be more than one)	**1**. Subsidy, **2**. Non-availability of other fuel sources, **3**. Social benefits/Prestige, **4**. Health benefits, **5**. Environmental benefits **6**. Economic benefits, **7**. Motivation from service provider **8**. Motivation from existing plant owners, **9**. Pressure from neighbors **10**= It saves fuel, **11**= It is clean energy, **12**= It is affordable **13**= It produces no smoke, **14**= It lasts long (durable), **15**= It cooks quickly, **16**= It makes use of farm wastes, **17**= Other: (specify) …………………………………..
What do you like most about the technology (biogas)? *Preferences*	**1**=It cooks quickly, **2**=It saves firewood and other fuels consumption, **3**=Saves time on gathering fuel wood, **4**= It agrees with our culture and traditions, **5**= It is portable, **6**=It is durable, **7**=One can use it in the main house, **8**= It does not create smoke, **9**=It adds flavor to food, **10**=It provides a clean cooking environment, **11**=It does not cause eyes to itch, **12**=It is a modern energy source, 13=Do not cause fire explosions, **14**= Other (specify)
What do you dislike most about the technology?	**1**= It is very expensive, **2**= Does not agree with our culture, **3**= It does not save on firewood and other fuels, **4**=It cooks slowly, **5**=It spoils frequently/quickly, **6**=Nowhere to repair, **7**=Not portable, **8**= It creates smoke, **9**=It requires too much labour and attention, **10**=It requires too much dung, **11**=It can easily cause gas leakages and fire accidents, **12**=Food doesn't taste as good, **13**=It causes itchy eyes and coughing, **14**=Do not dislike anything about the technology, **15**= Other (specify)--

6b. Source of funds for purchasing biogas

What was the total cost of your biogas plants including subsidy, if any, and your contribution including loans, if any?	
If subsidy was received, how much?	
How much cash did you contribute from your own sources?	
If there was no subsidy, would you have installed the plant [1= Yes, 0= No]	
What is your opinion on the cost of installation of your biogas plant? *[1= It is cheap, 2= It is reasonable/affordable, 3= It is quite expensive, 4= It is very expensive]*	
Did you take loan to install you biogas plant (s) [1= Yes, 0= No]	

Where did you take the loan from [1= Bank, 2= Micro-finance institutions, 3= SACCOs, 4= Local money lenders , 4= Friends and relatives, 5= Welfare groups, 6 = Others---------------	
Amount of loan borrowed (KShs)	
Interest rate per month (%)	
When was the loan taken (Year)	
Have you finished paying the loan [1= Yes, 0= No]	
How much is paid……………………. How much remaining to be paid…………….	
If loan not taken why? : [***1***. *You are well off,* ***2***. *You are against the philosophy of taking loans* ***3.*** *Interest rate is too high,* ***4***. *Processing for the loan is cumbersome,* ***5***. *Loan was not available/bank is far,* ***6***. *Taking loans degrade your social status,* ***7***. *Did not have Collateral,* ***8***.*Fear of failure to repay* ***9.*** *Other (specify)*	

7. User Satisfaction and Post Installation Behaviour

For how long have you been using the biogas (in months)	
How many stoves/gas lamps have you installed? **Number of stoves …………,** **Number of gas lamps………………**	
Is your biogas plant functioning? [1= Yes, 0= No]	
Are you satisfied with the functioning of the plant *[1= Yes,0= No]*	
If yes, what are the reasons for satisfaction? (answers can be more than one) *[**1**= Enough gas for cook/lighting, **2**= Trouble- free functioning of plant, **3**= Easy cooking/lighting, **4**= Economic benefit such as saving money, **5**= Health benefits (no smoke), **6**= Social benefits such as prestige, **7**= Environmental Benefits (less firewood), **8**= Workload reduction, **9**= Food cooked in gas is more tasty, **10**= Others (specify)]*	
If not satisfied, what are the reasons? (Answers can be more than one) ***[1****= Plant has failed, it does not work at all,* ***2****= Very little gas for cooking/lighting* ***3****=Not enough gas for cooking/lighting,* ***3****= Very difficult to operate,* ***4***. *Often encounter technical problems (leakages and breakages),* ***5****= More added work,* ***6****=Food cooked in gas is not as tasty,* ***7****=Others (specify)*	
Have you experienced any problems with your biogas plant? *[1= Yes, 0= No]*	
If Yes, what Problems ………	
Have your plant failed at any one time [1=Yes 0=No]	
If yes, what caused the failure? *[**1**= Poor workmanship during construction, **2**= Sub-standard quality of construction materials and appliances, **3**= Poor operation (over fed,*	

under-feed, more water, less water), ***4****= Poor maintenance/ No maintenance service available,* ***5****=Non-availability of spare parts,* ***6****= Natural/manmade disasters,* ***7****= Toilet attachment in plant was considered to be un-sacred,* ***8****= Slurry entered into the gas pipe,* ***9****= Water collected in pipe clogged it,* ***10****= Higher water table/flooding during rainy season,* ***11****= Others (specify)]*	
If plant has failed, for how long was the plant defunct? *[****1****= Less than a month,* ***2****= 1 to 6 months,* ***3****= 7 to 12 months,* ***4****=More than 12 months]*	
How often do you feed dung into the biogas plant? *[1= Daily, 2= Once in two days, 3=Once in three days, 4=Once in four days, 5= Others (specify)]*	
If daily, how many times 1=Once, 2=Two times, 3=Three times, 4=Other	
How much dung is feed at one feeding (in kgs)?	
Do you feed other substrate besides dung?*[1= No, 2= Kitchen and household wastes, 3= Human excreta, 4= Poultry droppings, 5= Agricultural wastes, 6= Other (specify)]*	
How much water do you mix the dung with? [*1= More than the volume of dung, 2= Equal to the volume of dung, 3= Less than the volume of dung/ poultry dropping*]	
Do you know how much dung is required to be feed into your plant daily? [kg]	

Biogas Energy Consumption

How long is the gas burnt in a day?

Burner	**Morning (hrs)**	**Afternoon**	**Evening**	**Night**
Stove				
Gas lamp				

Ideally, how many hours of as gas burning do you think would be enough to meet your cooking and lighting needs?

Burner	**Morning (hrs)**	**Afternoon**	**Evening**	**Night**
Stove				
Gas lamp				

Is gas enough for cooking and lighting? [1=Yes, 0=No]

If not sufficient, what are the main reasons*? [1. Small plant size, 2. Under-fed plants*
3. Over-fed plants, 4. Plants not regularly fed, 5. Less gas production due to defective construction, 6. Less gas due to defective operation and maintenance, 7. Less gas production during winter months, 8. Others (specify)
9. Do not know]

If gas not enough, for how many months in a year is the gas enough?

How many meals do you cook on average per day?

Has there been any change in the type of food you cook or where you cook from since you installed the biogas? [1= Yes, 0= No]

If Yes, please explain…………………………………………………………………………………………..

Have you experienced any advantages of biogas over other conventional fuel sources?
[1. No, 2. Less costly, 3. Comfortable and easy to operate, 4. Environment friendly, 5. More advanced and energy efficient, 6. Others (specify)]

8. Energy Sources and Use, Before and After Installation of Biogas

8a. Firewood sources and acquisition

Firewood sources	**Before Installation of Biogas**				**After Installation of Biogas**			
	Amount in Kg (weekly)	Time spent sourcing (hours in a week)	Average distance to collection point	Price (KShs)	Amount in Kg (weekly)	Time spent sourcing (hours in a week)	Average distance to collection point	Price (KShs)
Collected from forests								
Collected from private land								
Purchased								

8bi. Energy consumption and savings

Energy Type	**Average monthly consumption**							
	Before Installation of Biogas				**After Installation of Biogas**			
	Total Amount	% used for cooking	% used for lighting	Others (specify)	**Total Amount**	% used for cooking	% used for lighting	Others (specify)
Firewood (Kgs)								
Charcoal (kgs)								
Crop Residues								

(kgs)								
Animal Dung (kgs)								
Electricity (KShs)								
LPG (kgs)								
Kerosene (Litres)								
Biogas (kgs)								
Others (Specify)								

8b2. Expenditure and savings from fuel use before and after installation of the Biogas plant

Energy Type	**Average monthly expenditure and savings in KShs**		
	Before installation	**After installation**	**Net Savings**
Firewood (Kgs)			
Charcoal (kgs)			
Crop Residues (kgs)			
Animal Dung (kgs)			
Electricity (KShs)			
LPG (kgs)			
Kerosene (Litres)			
Biogas (kgs)			
Others (Specify)			

9. Health and Sanitation

9.1 Energy/Fire Systems and Health

9.10What type of fire system/device were you using before installation of biogas?	**1**. Open 3-stone fire **2**. Charcoal Jiko **3**. Kerosene stove **4**. Other ………………
9.11 Did your old system produce more smoke, less smoke, or the same amount of smoke compared with the biogas stove?	**1**. More **2**. Less **3**. The same **4**. Not sure
9.12 Did you feel dizziness or headache when cooking with the old device	**1**. Yes **2**. No **3**. Not sure
9.13 Do you feel dizzy/headache when cooking with the biogas energy?	**1.** Yes **2.** No **3**. Not sure
9.14 Of the two devices, which one made you feel dizzier?	**1.**Old device **2**. Biogas one
9.15 Do you regularly experience coughing or itchy eyes when cooking on the old device?	**1**. Yes **2**. No **3**. Not sure
9.16 Do you regularly experience coughing or itchy eyes when cooking with the biogas energy?	**1.** Yes **2**. No 3. Not sure
917 Of the two, which make you experience more coughing or itchy eyes?	**1.**Old device **2**. Biogas one
9.18 What are the main benefits of biogas energy related to health and hygiene? *[1= Liberation from smoke borne diseases, 2= Reduction in burning cases, 3= Absence of black soot in kitchen/house]*	
9.19 What are the main problems of biogas plants related to health and hygiene?	

9.2i Health problems related to fuel use before installation of biogas

Major health Problems	**Major victims***[1= Male adults, 2= female adults, 3= Male children, 4= female children,5= infants less than 5 years]*	**Frequency per year**	**Average Health Expenses per year**
Coughing and other respiratory problems			

Itchy eye			
Burns			
Dysentery/ diarrhoea			
Bad odour/ smell			
Others			

9.2ii Health problems related to fuel use after installation of biogas

Major health Problems	**Major victims***[1= Male adults, 2= female adults, 3= Male children, 4= female children 5= infants less than 5 years]*	**Frequency per year**	**Average Health Expenses per year**
Coughing and other respiratory problems			
Itchy eye			
Burns			
Dysentery/ diarrhoea			
Bad odour/ smell			
Others			

10. Time savings and the Social Economic Implications

Are you spending more, less, or the same amount of time on gathering firewood with the use of biogas	1. More 2. Less 3. Same
If saving time, how much time on average do you save in a week (hours)?	………………………
Does use of biogas energy save you time with?	1. Firewood gathering 2. Cooking and heating 3. Other………………. 4. No time saved at all
What do you do **with the saved time** that you did not do before	1. Farming 2. Feeding livestock 3. Children go to school 4. Fetching water

	5. Work for pay 6. Spend more time with family 7 Household chores 8. Others ………………………
Has biogas technology been useful to your family, and if yes, how has it improved your household life?	**………………………………..** **…………………………………** **………………………………….**

11. Biogas labour, decision-making and management

Who in the household took the decision to install the biogas plant [(**1**) *Male head* (**2**) *Female head* (**3**) *Male child* (**4**) *female child* (**5**) *Joint* (**6**) *Other*

Please indicate who mainly manages or contributes labour to various aspects of biogas production in the household

Main labour component	Main source of labour (*1) Male head (2) Female head (3) Male child (4) female child (5) Hired labour (6) Other*	**Number of persons handling per day**	**Time used per day/ per month**	**Cost of labour *[if hired labou is used]***
Biogas installation				
Transport of dung to biogas plant				
Mixing dung and water				
Feeding dung in digester				
Gas piping, opening and closing valves				
Maintenance and repairs of digester				
Removal of slurry				
Other labor				

How would you like the biogas energy technology improved?

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

…………………………………………………………………………………………………
…

12. Use of slurry

12.1 How much slurry does your digester generate per week (litres)	
12.2 Do you use slurry (by-product from the digester) on farm *[1=Yes,0= No]*	
12.3 If no, what do you do to the slurry? *[1= Sell to others, 2= Give out to others, 3= Drain to water courses or drains, 4=Use as fish feed, 7= Use for irrigation]*	
12. 4 If you do not use the slurry, why *[1= It has lesser nutrient value, 2= It is difficult to use, 3= People are reluctant to use the slurry from latrine attached plants, 4= No land to use, 5= Others (specify)]*	
12.5 What is your experience with bio-slurry in influencing crop yields? *[1= Same as Farm-yard manure (FYM), 2= Better than FYM , 3= Worse than FYM]*	
12.6 How much chemical fertilizer did you use **Before the installation** of you biogas plant? (kg)…………………….. **After installation** of the plant…………………………………………	

13. Awareness, Training and Capacity Needs in Biogas

13.1. Has anyone in your family received training on operation and maintenance of biogas plants?
[1=Yes,0= No]

13.2 What is the type of training that was received?

*[**1**. No training received, **2**. Training not provided but, leaflet/booklet/manual provided, **3**. Short orientation by mason/technician, **4.** Half/One day training provided by service provider, **5**. Short term training (7days or less) e.g. on Operations and Maintainance, **6**. On the spot instructions from mason/company supervisors etc., 7. Others (specify)]*

13.3 If you were trained in biogas, in what topics were you trained. List here

13.4 Did your knowledge of the subject matter increase during the training? [1=Yes, 0= No]

13.5 Have you used your skills and knowledge from the training in one or more of the following ways?

Please fill this table

Areas of application (*Tick all applicable)*	Have you been trained in the following areas: [1=Yes,0= No]	When were you trained [Year]	Type of training received *[1= leaflet/booklet/manual provided, 2. Short orientation by mason/technician, 4. Half/One da training provided by service provider, 5. Short term training (7days or less) e.g. Operations an Maintainance, 6. Field Demonstration, 7=from Neighbour friends)]*
Biogas installation			
Mixing dung and water			
Feeding dung in the digester			
Maintenance and repairs of digester			
Gas piping, opening and closing valves			
Training other neighbours			
Record management			
Others			

Areas of application	Were you satisfied with the training [1=Yes,0= No]	Which skills did you gain from the training	Which areas do you need more training *[can tick more than 1*
Biogas installation			
Mixing dung and water			
Feeding biomass in digester			
Maintenance and repairs of digester			
Gas piping, opening and closing valves			
Others			

Training other neighbours			
Record management			

12.6 Propose ways in which you could make more effective use of your knowledge and skills in biogas.

12.7 What is your opinion on the cost of installation of your biogas plant?
[1= It is cheap, 2= It is reasonable, 3= It is quite expensive, 4= It is very expensive].

What are the three major benefits that you are getting from your biogas plants?
1.
2.
3.

What are the three major disadvantages of biogas plants?
1.
2.
3.

What are your future plans with biogas use?
1.
2.

Do you intend to increase, reduce, or maintain your level of use of biogas?

Future intentions	**Quantity of plants**	**Reason for intended change**
Increase use		
Maintain use		
Reduce use		
Diversify use [e.g. several functions]		
Abandon		

Thank You

Appendix III: Questionnaire Set-II (For Non Households without Biogas)

1. General Information:

Name of Respondent:.. HH (Owner) Name: ………….............................

Age of Respondent: .... Family Size:............... Farm size (acres) ....…

Mobile phone of respondent (HH)……………...

Email of respondent (HH)……………………………………………….……..

Village Name: ………………… Sub-Location……………… Location………………

Household ID………………….Interview Date…………………Interview Time.................

Type of house: [1= Mostly earthen, 2 = Mostly wooden, 3= Mostly concrete

Do you have electricity [1 = Yes, 0= No]

Roof type: [1= Mostly grass roof, 2=Mostly iron sheets, 3=Mostly brick

Type of toilet 1=Flush 2= Traditional pit latrine 3= Ventilated improved latrine 4=Others (specify)

2. Other Household Details

Question	**Response (circle or enter)**
Sex of the Household Head	1. Male 2. Female
Age of Household Head	………………………….
Marital status	1. Married 2. Single / Never married 3. Divorced / Separated 4. Widowed
What relationship do you have with the head of the household?	1. Wife 2. Husband 3. House Help 4. Daughter 5. Son 6. Other Relative (specify): ....
How many people live in your household and you cook for in a day	Enter number
How many children under 5 years old live in your household?	Enter number
What is your household's main source of income?	1. Farming 2. Own Business 3. Employment (Corporate, Government) 4. Temporary employment 5. Unemployed 6. Other (specify): ....….

3. Characteristics of Household Members

Member name	Age	Education [0=none, 1= primary, 2=secondary 3=tertiary]	Main occupation (*see codes below*)	Approximate income/month [0= None 1= 0-50,000, 2= 50,001-100,000, 3= Over 100000	Gender 1= Male 2= Female	Months living at home (last 12 months)	Number of hours operating biogas plant in a day

Codes for main occupation and main source of income: 1. Farming 2. Own business/self employed, 3. Salaried Position (corporate, government), 4. Temporary Employment,
5. Unemployed, 6. Student, 7. Other (specify):

4a. Information on Livestock Ownership

Livestock Type	**No. of animals**	**System of management** [1=Zero grazing, 2=Free range, 3=Tethering, 4=Semi Zero 5=Others…..]	**Types of feed** [1=Grasses, 2= Farm residues, 3= Fodder trees, 4= Napier grass, 5= Livestock feeds from shop 6= Kenya brewery residues (*machicha*), 7= Molasses, 8= Hay 9=Silage 10=Other	**Source of feed** 1= Own farm, 2= Purchased	**If purchased, give quantity (monthly)**		**Average monthly expenditure on feed (in KShs)**
					Qty	Unit	
Cattle							
Pig							
Goats							
Sheep							
Poultry							
Donkey							

Unit Codes							
1	90 kg bag	7	25 kg bag	13	Grams	19	Donkey load
2	Kgs	8	10 kg bag	14	wheelbarrow	20	Donkey cart load
3	Litre	9	Gorogoro	15	cart	21	Hand cart load
4	Crate	10	Tonnes	16	canter	22	Head load
5	Numbers	11	50 kg bag	17	pickup	23	Area in acres
6	Bunch (bananas)	12	Debe	18	2kg bag	24	Other (specify)

4b. Sales of livestock and livestock products:

Livestock Type	**Quantity sold**	**Months mainly sold** [1= January….., 12= December]	**Distance to product market (km)**	**Value of products sold (KShs)**
Cattle				
Pig				
Goats				
Sheep				
Poultry				
Donkey				
Milk (litres sold per day)				
Eggs (crates sold per week)				
Others				

5. Information on crop production

Main crops	**Plot size per crop (acre)**	**Production (last season) (kg)**	**Consumption (kg)**	**Sold amount (kg)**	**Value of products sold (KShs)**

How much manure do you produce in a week (in Kg)………………………………………

How do you make use of the manure *1=Apply to the farm 2= Sell 3=Leave it in heaps 4=Give to neighbours 5= Other (specify)*

Biogas Purchase, Installation and Use Decisions

Have you heard about biogas energy technology?	1. Yes 2. No
If yes, where did you get the information from?	1.Government/NGO 2 TVs/Radio/ News papers 3. Friend/neighbor 4 Exhibition/promotion 5. Hardware/supermarket cages 6. Other (specify) …………………………………….
Why have you not installed biogas?	1. Not aware of it/Lack of information 2. It is very expensive 3. It goes against our traditions and cultures that sees it as a taboo to handle wastes 4. It requires too much waste 5. It can easily cause gas leakages and fire accidents 6. It doesn't not help save on firewood and other fuels 7. It cooks slowly 8. It spoils frequently/quickly 9. Nowhere to repair 10. It requires too much labour and attention 11. Do not know how it works 12. Other (specify) ....
Would you like to own a biogas plant in your home?	1. Yes 0. No
Would you be willing to pay for the cost of installation and maintenance of the biogas	1. Yes 0. No

plant?	
How much money would you be willing to spend on biogas installation and maintenance	**1**= Nil, **2**= 1-25,000, **3**=25,001 -50,000, **4**=50001 -75,000, **5**=75,001=100,000, **6**=over 100,000+

7. Fuel sources and consumption patterns

Firewood sources	**Amount in Kg (weekly)**	**Time spent sourcing (hours in a week)**	**Average distance to collection**	**Price**
Collected from forests				
Collected from private land				
Purchased				

Energy Type	**Average monthly consumption**		**% Amount used in**		
	Amount	**Price**	**Cooking**	**Lighting**	**Others (Specify)**
Firewood (Kgs)					
Charcoal (kgs)					
Crop Residues					
Dry animal Dung					
Electricity (KShs)					
LPG gas (kgs)					
Kerosene (Litres)					
Others (Specify)					

9. Health and Sanitation

What type of cooking stove do you use?	……………………..
Does it produce smoke?	1. Yes 2. No 3. Not sure
Did you feel dizzy or headache when cooking?	1. Yes 2. No 3. Not sure
Did you regularly experience coughing or itchy eyes when cooking?	1. Yes 2. No 3. Not sure

Major Health Problems	**Major victims** *[1= Male adults, 2= female adults, 3= Male children, 4= female children,5= infants less than 5 years]*	**Frequency per year**	**Average Health Expenses per year**
Coughing and other respiratory problems			
Itchy eyes			
Diarrhoea/Dysentery			
Burns			
Others			

Thank You