Thesis

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ESTABLISHING BASELINE AND OPTIMAL GAS PRODUCTION BY FIXED DOME BIOGAS PLANTS FOR CLIMATE CHANGE MITIGATION AND CARBON TRADE BY FARMERS IN KENYA

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Jecinta Wairimu Mwirigi

A Thesis Submitted to the Graduate School in Partial Fulfillment for the Requirements of the Award of Doctor of Philosophy Degree in Environmental Science of Egerton University

Egerton University

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DECLARATION AND APPROVAL

Declaration

I hereby declare that this research is my original work and to the best of my knowledge it has not been presented for an award of a degree or diploma in this or any other university

Jecinta Wairimu Mwirigi

NM12/0244/09

Signature: …………………….. Date: …………………………..

Thesis Approval

This thesis has been presented with our approval as University supervisors

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DEDICATION

This thesis is dedicated to my niece Julia and daughters Mercy and Monica for their continued moral support and encouragement throughout the study period.

ACKNOWLEDGEMENT

The successful completion of this study benefited from the input of various people and institutions, all of whom I cannot name here. However, I will single out a few for special mention.

First, I extend my gratitude to Egerton University for not only offering me an opportunity to study in the institution but also due to its financial contribution towards the research. Second my sincere thanks go to the National Council for Science and Technology (NCST) and Codesria Small Grants Programme for Thesis Writing for their financial support.

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Installation of the gas meters proved to be a considerable challenge that was surmounted by the devotion of the technicians. Further, the enormous task of tracing the biogas plant owners involved a lot of travelling and John volunteered to be a driver. To them all, I say thank you. Farmers in the study region judiciously entered data into the provided forms and they also promptly provided any information on issues requiring clarification while the Nakuru Meteorological Station provided timely weather reports. I, therefore, extend my heartfelt appreciation to them.

Last but not least, I acknowledge with gratitude, services offered by a host of people some of them known and others unknown to me personally but who all the same made this research possible.

ABSTRACT

While carbon dioxide (CO_2) from industrial and transport activities pose a global warming and climate change challenge to the developed countries, methane from agricultural/livestock production practices might have a similar effect in the developing countries. Therefore, there is a need for profitable emission reduction measures for methane, such as the carbon trade. Baseline emissions as well as proof that the planned emission reductions would not occur without the additional incentive provided by emission reductions credits, a concept known as "additionality", are a prerequisite for carbon trade through the Clean Development Mechanism (CDM). The current study, therefore, is aimed at measuring gas production by the various sizes of fixed dome biogas plants in the Bahati area as a way of establishing the baseline information. It also examined the effect of 7 variables on gas production with the aim of optimizing gas production from the same plants. These factors include the size of the plant and the number of cattle owned by the household (HH). The study employed the case study research design method with a target population of 63 functional fixed dome biogas plants in the Bahati area. Quantative data was generated and analyzed through descriptive and inferential statistics. The study showed that the current biogas plants are too large for the available waste and that it is possible to reduce the sizes of majority of the plants (98%) that were between 8 and 16m^3 to smaller sizes of 2 to 6 m^3 without affecting the amount of gas they produce. To come up with these sizes, the study established a formula Z=0.6Y where Z is the size of the digester, 0.6 is a constant and Y is the number of cattle owned by a HH. Since it is not cost effective to reduce the size of the current plants, it was concluded that this research will be of use to upcoming biogas units. The study recommends a new concept to "additionality" which will be achieved through use of the formula in estimating the digester sizes that will efficiently accommodate all available dung. Small plant sizes coupled with the financial assistance from CDM will make the plants affordable to the majority of farmers. This would lead to proliferation of digesters that are effective in climate change mitigation.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Climate change is increasingly recognized as one of the most critical challenges ever to face humankind thus requiring a global response embracing the needs and interests of all countries (Boer, 2008; Angus, 2010). As informed by the Intergovernmental Panel on Climate Change (IPCC), the main problem arises from the fact that human activities are the major contributing factors to the observed change through emissions of long lived greenhouse gases (GHGs) that lead to global warming (IPCC, 2007). In Kenya, impacts of climate change are already evident as droughts and floods in the country have become more frequent and intense (Ministry of Environment and Mineral Resources, 2009). The same source further states that the country has also seen increased average temperatures, more extreme hot days, and colder nights, successive crop failures, as well as the spread of vector-borne diseases such as malaria to places where the disease is not known to be endemic.

In June 1992, at the Rio Earth Summit, the international community acknowledged climate change as an important global issue. The meeting agreed upon a number of conventions of which one of them is the United Nations Framework Convention on Climate Change (UNFCCC).The Convention had two broad strategies, namely to mitigate and adapt to the effects of climate change. It set targets (Appendix 1) for the industrialized countries to stabilize their emissions (UNFCCC, 2008). However, these targets were not legally binding and according to the undated (n.d.) UNFCCC website on "Essential Background: The convention and the Protocol", the Kyoto Protocol came into force in 1997.

The major feature of the "Kyoto Protocol to the United Nations Framework Convention on Climate Change" was to set binding targets for 38 industrialized countries (also known as annex 1 countries) and the European community for reducing GHG emissions (UNFCCC, 1997). Article 3 of the Protocol requires that these countries reduce their GHGs by an average of five per cent against their 1990 levels over the five-year commitment period (2008-2012). This was after recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity. On the other hand, developing countries contribute less than 4 percent of global GHGs from fossil fuels (Pachauri, 2008). The major distinction between the Protocol and the Convention is that while the Convention encouraged industrialized countries to stabilize GHG emissions, the Protocol commits them to do so. As the National Environmental Management Authority (NEMA) reports, Kenya ratified the Convention in 1994 and the Protocol came into force in 2005 (NEMA, 2009).

One way of achieving the above commitment was through the CDM which according to the undated UNFCCC website, "The Marrakech Accords and Marrakech Declaration", was agreed upon in 2001. CDM is a market based tool that allows GHGs' emission-reduction (or emission removal) projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of carbon dioxide (Angus, 2010). These CERs can be traded and sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol. Article 12 of the protocol describes the purpose of the CDM as two fold that is to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention. In parallel, the emissions purchase through a voluntary carbon market has become a mainstream practice across business and individuals who although not having any regulatory mandate, aim to offset their emissions (Corbera *et al*., 2008; Nicola, 2007). The fears of Climate Change are still live and hence the Durban Climate Change Summit of 28th November - 9th December 2011 during which governments, including 35 industrialized countries, agreed to a second commitment of the Kyoto Protocol from January 1, 2013 (UNFCCC, 2011).

However, despite its success, CDM has not been a success everywhere in equal measure with Africa accounting for only 2.6 per cent of the projects registered to date (Mwaniki, 2011). Kenya had no approved CDM project by 2005 (Nyambiage, 2008) of the CDM projects of the Sub-Sahara African countries listed by the United Nations Environmental Programme (UNEP), it had 7 by August 2008 (UNEP, 2009). These include Sony and Mumias Sugar bagasse cogeneration projects, Kiambere, Sondu Miriu and Tana hydropower projects, Kepevu open cycle gas turbine and Olkalia II geothermal expansion. One common feature with all these projects is that they are large scale and located at single sites. Tipper (2002) had noted that focus on large scale projects like the forestry industry with relatively little attention being paid to small scale farmers, neglects the potential contribution of such farmers to addressing global climate change problems. It also cuts them out of a potentially valuable source of additional income. A new promising way of scaling up CDM is through registration of Programmes of Activities (Stehr, 2007). This means that the activities can be added to a programme over time and this can make a difference between installing a biogas plant in a single home and successfully constructing biogas plants in an entire community.

One enterprise that can make use of the CDM under the mandatory or voluntary markets is biogas technology that is practiced by livestock keepers and agro-processing industries such as slaughter houses. Biogas is produced when waste from ruminant animals is contained and allowed to decompose in an oxygen free environment. Biogas production is an effective way to reduce the level of GHG emissions from methane, which has a global warming potential 21 times that of carbon dioxide (Cunningham and Saigo, 2001). When manure is left in open lagoons, rather than being fed into a biogas digester, methane is emitted into the atmosphere. Biogas digestion on the other hand, allows for efficient processing of the manure, producing biogas, which is 50-80% methane and can be used by the household (HH) for cooking, lighting and electricity generation. Fixing methane, therefore, is in line with the Protocol. Note that if manure is instead composted, aerobic digestion will result in carbon dioxide emissions rather than methane.

Farming, especially in countries like Kenya, where agriculture is totally rainfall dependant, will be adversely affected by climate change with a likely reduction in yield of up to 50% by the year 2020 (IPCC, 2007) and considering that according to the Ministry of Livestock Development (MoLD), the Livestock Sub-sector contributes about 10% to the gross domestic product (MoLD, 2008), there is need for domestication of the protocol through the sub-sector and in the dairy cattle farming.

Dairy cattle farmers who keep their animals under the zero grazing method of farming are more likely to adopt biogas technology due to the ease with which they can collect cow dung (Mwirigi *et al*., 2009; ETC Group, 2007). They, therefore, have a high potential for CDM. However, CDM activities are demanding in terms of technical, financial and institutional resources available in Less Developed Countries (LDCs) and project proponents in LDCs face serious difficulties in obtaining data and undertaking expensive monitoring (Lopez *et al.*, 2009). This, as stated by the International Emission Trading Association, is despite the simplified methodologies that have been developed to suit them (IETA, 2008). It is against this backdrop that this study was conceptualized, and the results of this study may enable farmers to participate in CDM.

1.2 Statement of the Problem

Lack of data on the present GHG emissions and the projected emission reduction from small scale projects denies dairy farmers not only a chance to participate in the profitable market based climate change mitigation carbon trade, but it also excludes them from the income that can be accrued from such a business. As of 2011, Africa was hosting only 2.6 % of all total Clean Development (CDM) carbon trade projects. The rest were concentrated in the Asia and other developing countries. The main objective of this study was, therefore, to provide the gas production estimates from the fixed dome biogas plants in the Bahati area and further to optimize gas production from the same plants after understanding the effect of a number of variables on gas production. Optimizing methane production from the same waste implies that some of the methane that may have been left in the environment will now be flared and converted to carbon dioxide (CO_2) which has a global warming potential that is 21 times less that of methane.

1.3 Objectives of the Study

The broad objective of this study was to find out how much gas is produced by the various sizes of fixed dome biogas units in Bahati area as a way of establishing the baseline emissions. It further aimed at optimizing gas production by the same plants as a way of emission reduction. This was for purposes of climate change mitigation and carbon trade.

The specific objectives were to:

1. determine the biogas production by the different sizes of fixed dome biogas plants in the study area
2. assess the effect of several factors on biogas production by the fixed dome biogas plants in the study area. These factors are:
    - I. Biogas plant size
    - II. Biogas plant age
    - III. Household (HH) size
    - IV. Number of cattle owned by a HH

V. Biogas plant replenishment frequency

VI. Amount of cow dung fed into the digester

VII. Ambient temperature

1.4 Research Questions

1. How much gas do various sizes of fixed dome biogas plants produce?
2. What are the effects of the following factors on the amount of biogas produced by the fixed dome biogas plants in the study area?

    I. Plant size

    II. Plant age

    III. Household (HH) size

    IV. Number of cattle owned by a HH

    V. Plant replenishment frequency

    VI. Amount of cow dung fed into the digester

    VII. Ambient temperature

1.5 Justification/ Significance of the Study

1.5.1 Justification

Methane, which is the major constituent of biogas is a GHG that has a Global Warming Potential (GWP) that is 21 times that of carbon dioxide. Therefore the more methane that is converted to CO_2 through capture and flaring, the higher the emission reductions, the higher the number of Certified Emission Reductions(CERs) , and the higher the revenues from the CDM

However, the biogas units that convert organic matter to biogas are expensive (Mwirigi, 2011) and thus unaffordable to most dairy cattle farmers. The practice therefore is to heap the manure next to the cow shed and let it rot both aerobically and anaerobically if decomposition is anaerobic, this will release methane to the environment. Several formulae on calculation of methane released from organic matter are documented as in Abarghaz *et al.,(*2011). The manure is mostly from adult cattle that are already in-calf or producing milk. Younger animals and bulls have been found to be uneconomical in the zero-grazing systems (Lanyasunya *et al*.,2006) Optimizing biogas production implies that small sized digesters might become effective in HH energy supply while the smaller sizes result in lower construction costs. The additional support of the CDM is likely to produce the lowest construction prices that are affordable to majority of the farmers thus overcoming the financial barrier that has hindered adoption of the technology.

1.5.2 Significance

The current Approved Methodologies (AMS) listed by UNFCCC on its website on "Approved SSC Methodologies", which include methodologies such AMD-III.D on methane recovery in animal manure management systems as well as AMD-III.R on methane recovery in agricultural activities at HH/small farm level, require expertise that is unaffordable to the poor farmers. These rules apply equally to non- Annex 1 or developing countries that include members of the Organization for Economic Cooperation and Development (OECD; Mexico and South Korea), large emerging economies (e.g., Brazil, China, India, South Africa), and Less Developed Countries (LDCs) like Angola, Bangladesh and Cambodia (Lopez *et al*, 2010). The result of such indiscriminate grouping as described by SNV and Practical Action (2012) is that the CDM has been unable to reduce the dependence of HHs in the LDCs on traditional biomass resources for energy supply.

A very basic way of estimating emission reduction by the poorer countries might be the only way for them to join the carbon trade. This is supported by Lopez *et al*. (2009) who suggested that in the absence of methodologies appropriate to the proposed CDM activities, project proponents must develop and submit new methodologies to the CDM executive board.

Once the farmers enter the carbon market, they will achieve the goals of the Kyoto Protocol as stipulated in the CDM that is emission reduction and sustainable development. Sustainable development has been classified as economic, social and environmental (Olsen & Fenhann, 2008). Gupta *et al*. (2008) has further differentiated sustainable development into direct and indirect benefits. Direct benefits are those directly derived from project activities and can include enhanced air quality, improved health, reduced fossil-fuel expenditure and technology transfer. Indirect benefits encompass poverty alleviation, job creation and useful by-products, which in this study, include the organic fertilizer (slurry) as well as improved waste management system. The latter is important because as animals have been concentrated and the numbers increased in individual enterprises, the quantity of manure requiring management has increased (Overcash *et al.*, 1983). Further, involvement of poor farmers could also pose a challenge to some of the developed countries that have been slow in ratifying the Kyoto Protocol and whose basis as stated by Elgar (2000) is lack of participation in climate change mitigation by the developing countries.

1.6 Scope and Assumptions of the Study

1.6.1 Scope

The study was carried out in Bahati location and its surroundings that include parts of Lanet and Dundori locations. Bahati and Dundori are in Nakuru North district while Lanet is in Nakuru district. The area was selected due to its high concentration of dairy cattle farmers who rear their animals under the zero grazing system and at the same time own fixed dome biogas plants; 63 out of 70 are functional. The fixed dome plant design has been found to be highly sustainable in the area, with a strong likelihood amongst farmers who rear animals under the zero grazing farming system to adopt biogas technology (Mwirigi, 2011). Furthermore, the plants have the desired characteristics for this study, different plant ages, capacities and replenishment frequencies. The plants' ages of the plants range from between one and fifteen years. Their volumes range between 8 m^3 to 35 m^3, mostly in multiples of 4, while the replenishment frequencies range from once a day to once a month. The HH sizes and the number of cattle that they own are also different and the effects of the above factors on gas production were assessed.

1.6.2 Assumptions

It had been assumed that the farmers will actively participate in the research. However, in order to enhance participation, a sensitization workshop was held for all the participants before the study commenced. During the meeting, farmers were informed of the need to participate in the research and how the results would be used for economic and environmental benefits through the CDM. Another assumption of the study was that each HH utilizes all the biogas produced by its plant in a day and, therefore, the daily gas production is equivalent to gas utilization.

1.7 Definition of Terms

In this study, the following terms were operationally defined as follows:

Additionality: Additionality is a concept that addresses the question of whether the CDM related project would have happened even in the absence of revenue from carbon credits.

Adult/mature dairy cattle: Cattle being used principally for milk production

Biogas: Refers to the gas produced through microbial degradation of plant or animal materials in the absence of air (anaerobic conditions)

Biogas plant: Plant refers to the large machinery that is used in industrial processes. In this study, biogas plant refers to the whole biogas producing and supply system that includes the digester and gas piping up to the house. In the study area, the digester design and herein referred to as "plant", is the fixed dome and is also interchangeably referred to as biogas plant, biogas unit or digester.

Biogas Technology: Refers to the process of harnessing biogas in artificially created conditions.

CDM: Clean development Mechanisms are in reference to projects that emit zero or less GHGs. It also includes projects that remove GHGs from the environment such as forests.

CER: A Certified Emission Reduction is equivalent to one tonne of carbon dioxide

Climate Change: Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. In the UNFCCC usage, climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. In this study, climate change is as used by UNFCCC

Crediting Period: The crediting period refers to the 7 or 10 year period for which a registered CDM programme earns CERs. The 10 year term is not renewable while that of 7 years is renewable.

Dairy Cow: Mature cows that are producing milk in commercial quantities for human consumption.

Dairy Farming: Dairy farming is the animal husbandry enterprise for long-term production of milk usually from dairy cows but also from goats and sheep. In this study, it refers to dairy cattle farming.

Digester: Refers to the cow dung fermentation chamber of a biogas unit.

DOE: Designated Operational Entity is a third party that validates and subsequently requests registration of a CDM project. It also verifies emission reduction of a registered CDM project activity; certifies as appropriate and requests the CDM Executive Board to issue Certified Emission Reductions accordingly.

Feed stock/Feed material/Substrate, Raw materials: In this study they all refer to cow dung

GHGs: GHGs are gases such as carbon dioxide and methane which are responsible for global warming and climate change

Household : A "household" generally refers to a group of individuals who eat together and live under one roof or in different houses within the same compound and share most of the domestic responsibilities as a means of survival. This study defines a HH in that context

IPCC: Intergovernmental Panel on Climate Change (IPCC) refers to the IPCC that was established in 1988 jointly by the world Meteorological Organization and the United Nations Environmental Programme.

Kyoto Unit: Refers to one CER which is equivalent to one tonne of carbon dioxide.

Plant Age: Refers to the number of years of the plant from construction to the time of the study

PPR: Polypropylene random copolymer (PPR) material which is a thermoplastic polymer that turns into a liquid when heated and freezes to a very glassy state when cooled sufficiently

Replenishment/Feeding Frequency (FF): Refers to the regular rate of adding cow dung to a digester for example once daily or once a week.

Slurry: Refers to a thick liquid consisting of water mixed with animal waste. In this study it refers to the digested waste produced during biogas production.

The convention: Refers to the United Nations Framework Convention on Climate Change (UNFCCC) that was adopted in New York on 9th May 1992.

The Protocol: Refers to the Kyoto Protocol

VCU: A Verified Carbon Unit is equivalent to one tonne of carbon dioxide. It is similar to a CER but undergoes a less rigorous registration process. It is also voluntarily traded unlike the CER which is mandatory

CHAPTER TWO

LITERATURE REVIEW

2.1 Carbon Trade

International trade in GHG reductions is now a large and rapidly growing market that is motivated by requirements of the Kyoto Protocol and also by regional programs, voluntary initiatives, governments, private companies, and individuals who have collectively committed billions of dollars to buy emission reductions (Green Markets international, 2007). The Kyoto Protocol, signed in December 1997 specifies binding emission reduction targets for anthropogenic GHG emissions for countries listed in its Annex B. According to UNFCCC (1998), the Protocol includes three flexible emissions trading mechanisms that are listed in article 17 on Joint Implementation (JI), article 6 on emissions trading and article 12 on the CDM.

Whereas emissions trading and JI apply to signatories listed in Annex 1 of the United Nations Framework Convention on Climate Change (UNFCCC), the CDM was developed as a means of involving developing countries in global climate change mitigation policies. Despite its good start, there is still a great deal of confusion about CDM, indeed about emissions trading in general, and its role in combating climate change and contributing to sustainable development (Stehr, 2007).

Emission trading is an administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. It is sometimes called cap and trade. The process of helping someone else to emit less GHGs is referred to as carbon offsetting that leads to two distinct types of Carbon Credits, Carbon Offset Credits (COCs) and Carbon Reduction Credits (CRCs). COCs consist of clean forms of energy production, wind, solar, hydro and biofuels. CRCs consists of the collection and storage of carbon from the atmosphere through biosequestration (reforestation, forestation), ocean and soil collection and storage efforts. Both approaches are recognized as effective ways to reduce the Global Carbon Emissions crisis. However, there are few registered reforestation and afforestation projects due to uncertainties regarding issues of permanence of emission reductions from forest sinks (Lopez, 2009).

As Nicola (2007) and Janson-Smith (2008) describe them, offsets can be Kyoto instruments in the form of Certified Emission Reductions (CERs), Emission Reduction Units (ERUs) or European Allowances (EUAs), but very often companies or individuals buy Verified Carbon Units (VCUs). The VCUs and the CERs are similar and the main difference is that while the VCUs are voluntarily traded, the CERs are mandatory (Corbera *et al.*, 2008). Other differences include the selling prices. CERs command a higher price than VCUs, as buyers are guaranteed a credible emissions reduction established through internationally accepted standards. According to Carbon Positive (October, 2009), a business that develops sustainable agro-forestry and bio-energy ventures in non-industrialized countries, a CER was selling at 13.76 Euros(Kshs 1,523) in October 2009, while a VCU was selling at $5.8(Kshs 430). However, the prices of CERs are very volatile and can vary from 7 to 32 Euros per CER (Point Carbon, 2006), quoted by Bayon *et al.*(2008). The cost of production is also different. For example, setting up a carbon offset project approved by CDM Executive Board under the Kyoto Protocol costs up to US$350,000(Kolmus *et al.*, 2008), quoted by Bayon *et al.*(2008).

While the history of the mandatory CDM goes back to 1992 when the international community acknowledged climate change as an important global issue at the Earth Summit, the history of the voluntary markets pre-dates all regulated carbon markets. The world's first carbon offset deal was brokered in 1989 when AES corp., an American electricity company invested in agro-forestry in Guatemala (Hawn, 2005; Corbera *et al*, 2008).

Although nobody has the exact numbers on the size of the global voluntary carbon markets, most think they have grown rapidly since 2006 (Bayon *et al.*, 2008) but while maturing quickly, the voluntary markets remains small, transacting roughly 2 % of the Kyoto markets. The registry and standardization of the voluntary carbon markets is through the Verified Carbon Standard Association (VCSA, 2011), while that of the mandatory one is through the CDM Executive Board as stipulated in the undated UNFCCC website on "Baseline and monitoring methodologies".

CDM came into force in Marrakech in 2001, and by May 2009 the undated UNFCCC website on "CDM statistics" was indicating that there were more than 4,200 CDM projects in the pipeline. The same source states that CDMs are expected to raise more than 2.9 billion CERs by the end of the commitment period (2012).

Potential investors and buyers in CDM projects include private sector firms, governments, and funds that pool money to purchase CERs (Lopez *et al*., 2009). Hyera (2008) quotes Government carbon funds to include the Japan Carbon Fund while private sector carbon funds include Ecosecurities-Standard Bank Carbon Facility. Examples of international organizations are the World Bank and African Development Bank. Hyera (2008) further includes in the list of buyers, the traders/brokers such as Barclays and finally the end users, such as Mitsubishi. The private sector accounted for almost 90% of the voluntary carbon market transaction volumes in year 2008 while buyers from the European Union dominated the CDM market with about 87 % of the purchase volumes (Capoor & Ambrosi, 2009).

In the context of promoting a more equal regional distribution of CDM projects, the CDM EB has identified potential synergy between CDM and microfinance activities in the least developed countries (Stehr, 2007). This collaboration could develop into a major initiative, in combination with a programme-of-activities (PoA) approach to expand CDM'S usefulness to the poor. By the year 2007, the Kenya Commercial Bank (KCB) was the only private finance institution to express interest in participating in CDM finance in Kenya but no specific information was available (DEG, 2007). However, as far back as the year 2007, international institutions such as The Deutche Investitions-und Entwicklungsgesellschaft mbh (DEG) and CantorCO2e were willing to take over the complete management of the certification process as well as bearing transaction costs contingent on success e.g. for Project Idea Notes (PINs) and Project Design Documents (PDD) as well as validation. This is in addition to financing commercially viable projects (DEG, 2007; Nicola, 2007). The data provided by the results of the current study will enable the farmers from the study area and other similar areas in Kenya to participate in CDM or the voluntary carbon trade.

2.2 Climate Change and the Greenhouse Gases (GHGs)

The Kyoto Protocol shares the ultimate objective of the Convention that is to stabilize atmospheric concentrations of GHGs at a level that will prevent dangerous interference with the climate system (UNFCCC, 2008). The six GHGs that the Kyoto Protocol aims at controlling are listed in annex A of the Protocol (UNFCCC, 1997). These gases are carbon dioxide (CO_2) - produced by the burning of fossil fuel and cutting down of forests, methane (CH_4) - produced by anaerobic decomposition of organic wastes, coal mining and released by, for example, oil drilling, nitrous oxide (N_2O) - from application of fertilizers, hydroflourocarbons (HFCs) - a category of industrial gases used to replace chlorofluro carbons (CFCs) that was previously used for refrigeration and which the Montreal protocol insists should be phased out, perflourocarbons (PFCs) - a category of industrial gases also used to replace CFCs and finally, sulphur hexa fluoride (SF6) - another industrial gas.

There has been an imbalance in the spatial distribution of the CDM market due to concentration of HFCs and N_2O which account for 44% of expected emission reductions by 2012 but only 4% of projects (Lopex *et al*., 2009). This is because the CDM activities take advantage of the high global warming potential[1] of HFCs and N_2O gases, this approach has been criticized as an end-pipe fix with few sustainable development benefits (Schwank, 2004; Olsen and Fenhann, 2008). Compared to renewable energy, these projects produce large quantities of CERs at lower cost and are thus financially more attractive. Lopez *et al*.(2009) had noted that the opportunities for GHG mitigation in the developing countries do not lie in large industrial conglomerates, as they are nonexistent, but in cottage industries and HH activities. It is, therefore, the CH_4 which is a constituent of biogas that is of interest in this study. HH biogas projects have been successfully exploited in India for CDM (Mukherjee, 2007), but not in Africa.

The Food and Agricultural organization of the United Nations (FAO) estimates that worldwide, livestock production occupies 70% of all land used for agriculture, or 30% of the ice-free land surface of the Earth (FAO, 2006). In addition, information from the same source reports that Scientists attribute more than 18% of anthropogenic GHG emissions to livestock and livestock-related activities, such as deforestation and increasingly fuel-intensive farming practices. It is important, therefore, to control GHG emissions from the dairy sector. The potential of biogas technology in CDM involvement is high in Kenya as the Energy Technology & Controls Ltd) (ETC) group estimates that in only five districts namely

[1] Climate Change (1995) lists the global warming potentials of the greenhouse gases(GHGs) as 23900 for SF6, 140-1700 for HFCs, 6500-9200 for PFCs, 21 for CH_4 and 310 for N_2O

Kakamega, Kiambu, Kisii, Nakuru, and Nyandarua, there is a combined potential of up to 38,000 biogas units (ETC, 2007). The current study has demonstrated that by use of a formula to calculate the recommended plant size, a large increase in adoption of the technology is likely to take place.

2.3 The CDM Process

The CDM project cycle is a complex process (Lopez, 2010) and the modalities, procedures, and the growing body of guidance, tools and clarification of how projects can actually CERs, are even more complex (Stehr, 2007). As described in the undated UNFCCC website on “Guidelines, Guidance and Clarifications”, the CDM process has five steps: (1) project design, (2) validation/registration (3) monitoring, (4) verification/certification and (5) issuance of Certified Emission Reductions

In the project design, the process starts with identification of a project with a CDM potential and then preparation of a Project Idea Note (PIN) which is further developed to a Project Design Document (PDD). International acceptance of a CDM project first requires approval at the national level, consistent with the country’s domestic laws and policy priorities. The Designated National Authority (DNA) issues this approval and in Kenya, the National Environmental Management Authority (NEMA) is the DNA (Mwinzi, 2009). Project participants then submit the PDD to the Executive Board (EB). The CDM project must use methodologies approved by the EB as stipulated in the UNFCCC website on “Baseline and monitoring methodologies”.

The validation/registration process is carried out by third party bodies known as Designated Operational Entities (DOEs). The UNFCCC website on “Designated Operational Entities” describes DOEs as either a domestic legal entity or an international organization accredited and designated, on a provisional basis until confirmed by the Executive Board (EB). The list of DOEs is available on the UNFCCC website on “CDM List of DOEs”. The same DOE may undertake validation, verification, and certification for small-scale projects, whereas full-scale projects require two different operational entities, which would entail higher consultancy fees (Lopez *et al*., 2010). This is one way of encouraging small scale projects to participate in CDM. The UNFCCC website on “Designated Operational Entities” lists their duties to include;

- Validation and subsequent request for registration of a proposed CDM project activity which is considered valid after 8 weeks if no request for review is made
- Verification of emission reduction of a registered CDM project activity, certification as appropriate and a request to the Board to issue CERs accordingly. The issuance is considered final 15 days after the request is made unless a request of review is made.

As indicated in the H section of the seventh conference of parties on the UNFCCC, Project participants shall include a monitoring plan as part of the project design document. This includes the collection and archiving of all relevant data necessary for estimating or measuring anthropogenic emissions by sources of GHGs occurring within the project; Quality assurance and control procedures for the monitoring process boundary during the crediting period (UNFCCC, 2002).

Verification/certification and issuance of CERs is also carried out by DOEs. The accreditation of DOEs is carried out by the EB in accordance with accreditation standards (UNFCCC, 2006). The EB also develops and maintains the CDM registry as well as developing and maintaining a publicly available database of CDM project activities containing information on registered project design documents, comments received, verification reports, its decisions and information on all CERs issued (UNFCCC, 2006). However, the CDM EB supervises the CDM under the authority and guidance of the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (COP/MOP), normally shortened to CMP and is fully accountable to the CMP.

Specialized expertise that is required to carry out the CDM process is not readily available in Kenya (Mwinzi, 2009) and the rates of external consultants are too expensive for project developers in poor countries (Stehr, 2007). Lopez *et al*. (2010) recommends that UNFCCC Secretariat establish a team of personnel that is able to perform the duties of private DOEs in order to lower the CDM overhead expenses that include travelling and labor costs. Data from this study can assist the local farmers and investors in developing a PDD and it can also be used in validation, verification and certification of the biogas project and therefore lower the overhead costs of the process to an affordable level for local farmers also.

2.4 Additionality and Baseline Information

Additionality

Article 12 of the Protocol includes another particularly important prerequisite for obtaining CERs. Reductions in emissions must be additional to any that would occur in the absence of the certified project activity (UNFCCC, 1997). The additionality criterion is, therefore, one of the key issues of the CDM under the Kyoto Protocol (Shrurestha and Timilsina, 2002). Meyers (1999) notes that establishing a workable way to judge whether reductions in emissions are additional to what would happen without the CDM activity is perhaps the most vexing challenge facing the CDM and he further states that to follow to the letter of article 12.5 is impossible. Ideally, the CDM should provide a reasonable degree of real (additional) emissions reductions without constraining investment in projects and as stated by Meyers (1999), if the criteria for judging additionality are too lenient, then CDM will mainly produce free riding and if they are too strict, they will hinder investment in projects and the financial flows expected by the developing countries will not occur.

The UNFCCC on its website; "Tool for the demonstration and assessment of additionality" provides for a step-wise approach to demonstrate and assess additionality. However, the same source states that this tool is not mandatory for project participants when proposing new methodologies. This implies that a project developer can develop his methodology of determining additionality. Determining additionality in biogas production is provided for under the UNFCCC website on "Indicative simplified baseline and monitoring methodologies for selected small-scale CDM project activity categories: Type III- Other project activities" and this involves comparing the additionality brought about by constructing or installing a biogas plant by a project participant who has been using other types of fuel, like fuel wood or fossil fuel, which act as the baseline scenario for the project participant. This study attempts to demonstrate additionality in biogas production by improving their efficiency.

Baseline

CDM projects should result in "measurable" reductions in GHGs. The concept of "measurable" reduction is based on a comparison with some defined level of GHG emissions. This comparative level, against which the reductions of GHG emissions due to a CDM project are measured, is termed "Baseline" (UNEP, 2005). The Marrakech Accord defines the baseline for a CDM project activity as "the scenario that reasonably represents the anthropogenic emissions by sources of GHGs that would occur in the absence of the proposed CDM project activity". The proposed CDM project will result in reduction of GHG emissions only if the GHG emissions from the proposed CDM project are lower than the baseline. Therefore, in order to determine what is "additional", a baseline must be established. In its "Combined tool to identify the baseline scenario and demonstrate additionality", the undated UNFCCC website provides for a step-wise approach to identify the baseline scenario and simultaneously demonstrate additionality. In that tool, the assumption was that the farmer's life without a biogas unit is the baseline scenario, as the animal waste emits methane, which is subsequently released to the environment. In the same set-up, additionality is achieved through construction of a biogas unit and the ensuing utilization of the GHG (methane) for cooking. Figure 1 displays how baseline and additionality are estimated. In the current study, the baseline scenario is the biogas units that is not producing optimally due to the effect of the factors under study. Manipulating the factors so as to increase the efficiency of the digesters is the additionality aspect as the extra methane will be flared and reduced to carbon dioxide that is less potent in causing global warming.

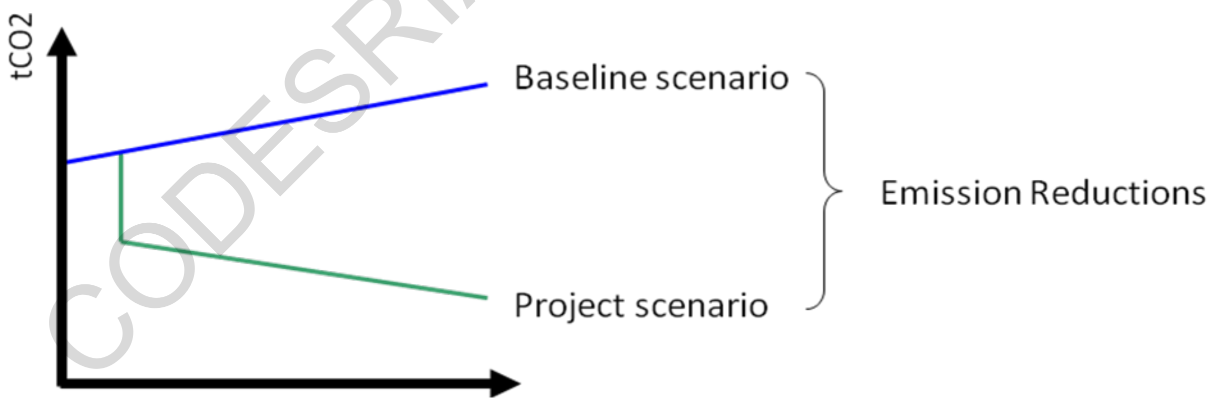


Figure 1: Emission reductions (additionality) from a CDM project

Source: Woods, 2012

2.5 Why Africa has not benefited from the CDM Trade

Since its introduction, CDM projects are largely concentrated in a few developing countries (Angus, 2010; Lopez *et al.*, 2009; Corbera *et al.*, 2008), with Africa hosting less than 2% of all current CDM projects (URC and UNEP, 2010; Olawuyi, 2010). As of October 2007, Asia and the Pacific had 1860 projects in the CDM pipeline(72% of all), Latin America had 601 projects(24%), North America and Middle East had 34 projects (1.5%), Sub-Sahara had 33(1.5%), and Non- Annex 1 Europe and Central Asia had 23 projects (van der Gaast *et al.*,2008). Causes of limited participation in CDM by LDCs[2] include high economic and political risks and limited financial returns; small fragmented projects and the characteristics of the demand side of CDM markets (Lopez *et al*, 2009). Lack of training, policy frameworks, private sector engagement and national institutions to support the steps necessary to get a CDM project up and running effectively are other causes of the low participation in CDM projects by African countries (URC and UNEP, 2010).

In their concluding remarks during their search for greater participation of the LDCs in CDM through change of CDM rules, Lopez *et al*. (2009) stated that the participation of LDCs in CDM can be construed as largely symbolic, even if CDM activities were to be successfully expanded to LDCs. This, they explained, is because of the size and composition of the LDCs' national economies and domestic markets. Thus their contribution to global GHG mitigation efforts would remain insignificant. In addition, they noted that modifying the rules of the CDM as per their suggestions is unlikely to open a floodgate of registration of projects in LDCs because, beyond the CDM rules, financial and technical barriers remain significant obstacles to project development in LDCs. This study has provided information on biogas production so reducing the number of technical and financial barriers.

2.5.1 High economic and political risks and limited financial returns

According to World Bank (2008a) quoted in Lopez et al. (2009), most of the LDCs rank below the 30th percentile on the World Bank's 6 aggregate governance indicators. These pointers include voice and accountability, political stability and lack of violence/terrorism, government effectiveness, regulatory quality, rule of law and control of corruption. According to Freedom House (2008), only six LDCs, most of them small island states, are free in terms of political and civil liberties. Transparency International (2009) states that

[2] As quoted by Lopez *et al.* (2009), The United nations Social and Economic Council identify LDCs according to the following criteria: -A gross income per capita under U$750,
-Human Assets Index(nutrition, health, education, and adult literacy)
-Economic Vulnerability Index (instability of agricultural production and exports, limited manufacturing and modern services, export concentration, economic smallness, population displaced by natural disasters.
-A population of fewer than 75 million people.
To be included in the list, a country must satisfy the fourth criteria and at least two of the first three criteria in two consecutive reviews (UN-OHRLLS,2009)

LDCs perform poorly in corruption perception surveys, trailing at the bottom of the international ranking. Civil unrest, expropriation, breach of contract and other nonpayment, all contribute to increasing the political and economic risks confronting CDM project developers in LDCs (Lopez, *et al*., 2009). Kenya is listed in the category of developing countries in the World Bank's list of countries' development indicators (World Bank, 2008b). Empirical data that has been acquired through this survey provides reliable and credit worthy information that can be used by buyers of CERS.

2.5.2 Small fragmented projects

As stated by Lopez *et al.* (2009), there are limited industries and industrial processes in the LDCs and so limited emissions from these sectors. In addition, the energy and industrial and agricultural production in LDCs is fragmented among a range of small to medium enterprises, cottage industries and HH businesses, rather than in large commercial entities. According to Lopez and others, the opportunities for GHG mitigation in LDCs, therefore, do not lie in large industrial conglomerates, but in cottage industries and HH activities. With this assurance, the findings of this study create a CDM opportunity for HHs involved in dairy farming through the Programme of Activities (POA) as described by Stehr (2007).

2.5.3 Characteristics of the demand side of CDM markets and the market-based nature of CDM

The demand side of the CDM market includes the private sector, governments and funds that pool money to purchase CERs (Hyera, 2008; Lopez *et al*., 2009). From a buyer's perspective, in the primary CER market, it is financially more advantageous to secure CERs from a limited portfolio of large projects than to incur higher transactions costs with a multitude of small projects (Lopez *et al*., 2009). Thus, the demand of CERs has been biased in favor of large industrial opportunities or large scale projects to the detriment of smaller activities in agriculture and forestry. Data from this study will significantly reduce the overhead costs for a PDD for biogas PoAs in the country.

Studies on CDM have shown that countries that receive high foreign direct investment flows also attract a high number of CDM projects (Ellis *et al*., 2007). The low direct foreign interest of the LDCs could, therefore, explain the low participation in CDM projects as CDM is a business like any other trade (Corbela *et al*., 2008; Olawuyi, 2010).

2.5.4 Lack of training, policy frameworks, private sector engagement, national institutions and technical capacity

URC and UNEP (2010) is engaged in a wide range of programmes geared to supporting African countries' increased engagement in CDM activities after recognizing lack of training, policy frameworks and lack of national institutions for CDM implementation as some of the causes of low adoption of CDM in Africa. The Nairobi framework partners have the same goals (Kilani, 2010). Implementation of CDM in Kenya is hampered by factors such as absence of legislation framework, inadequate institutional framework, financial, technical and personnel capacity, insufficient local expertise, as well as lack of information and little public awareness of the opportunities afforded by CDM (DEG, 2007). Technical capacity is in short supply in the LDCs, as displayed by the number of accredited Designated Operating Entities (DOEs), of which 23 out of the total number of 26 accredited DOEs are headquartered in the industrialized countries as listed in the UNFCCC website on "List of DOEs". DOEs are required for validation/registration and verification/certification phases of the CDM project cycle (Lopez *et al*., 2009). Policy frameworks also contribute to low adoption of CDMs. In Kenya for example, the Kenya Climate Change Response Strategy (CCRS) was still in the draft form by the year 2009 (Ministry of Environment and Mineral Resources, 2009). Lack of institutional and project development expertise, suh as the Designated National Authorities (DNAs) has also hampered countries like Angola, Botswana, Malawi, Nigeria and Rwanda from being players in the carbon market (URC and UNEP, 2010). This study has given an estimate of the number of CERs that a farmer with 4 animals can generate in a year. This information can be of value to policy makers in realizing the carbon trade through biogas technology.

2.6 Factors that affect Gas Production by a Biogas Plant

Biogas is produced through microbial digestion of organic matter by four types of microorganisms in the absence of air (anaerobic conditions). A good example is given by Netherlands Development Organization (SNV) whereby bio-digesters convert animal manure, human excrement and biomass waste at the HH level into a combustible biogas and a potential organic fertilizer (SNV, 2004). These microorganisms are the hydrolytic, fermentative, acetogen and methanogen bacteria. The cycle of conversion, for example of cow dung into methane, is between 35-40 days (Malgavkar & Panandiker, 1986). The product of the above reaction is biogas, which consists of methane (50-80 Vol-%), carbon dioxide (20-50 Vol %), hydrogen sulphide (0.01-0.4 Vol %) plus traces of ammonia, hydrogen, nitrogen, oxygen and a by-product called slurry (Korbele, 2006). Pure methane is a colorless, odorless gas that burns with a blue flame but biogas does have a mild odour from the trace hydrogen sulphide (Hankins, 1989). Amongst its other uses, Biogas is used for cooking and lighting.

Biogas production from organic matter is affected by the presence of oxygen, toxins, temperature, pH, nutrient ratio, quality and quantity of the feedstuff for the digester, as well as the type and operation of the digester (Price & Paul, 1981; Koberle, 2006). The retention time of the feedstuff in the digester also affects gas production. Oxygen concentration of 0.1 Vol.1% is inhibiting to methane producing bacteria, while the optimal temperature is biphasic, which is mesophilic (32-42^{o}C) and thermophilic (50-58 ^{o}C). The optimal pH is between 7 and 8 (Fulford, 1988). The pH of cow dung is around 7 and the fixed dome digester design that was used in this study is airtight. In the current study, oxygen and pH were not expected to affect gas production; therefore they were not included in the study.

Although the effect of temperature on gas production by fixed dome plants has been determined at the laboratory level (Singh *et al.*, 1998), gas production from the same plant design during the various climatic conditions of the year has not been documented, hence this is included in this investigation.

A study carried out earlier on in the study area had shown that biogas plant owners have knowledge of the effects of toxic substances like antibiotics and pesticides on gas production (Mwirigi, 2011). Toxic substances were, therefore, not expected to affect gas production in the current study. Retention time (the number of days that the feed material remains in the digester) also affects the amount of gas produced. Fats and sugars in the substrate are digested within hours or a few days. Carbohydrates and proteins need up to 20-30 days to produce 80% of gas yield (Koberle, 2006). The frequency at which the digester is replenished determines the retention time of the feedstock. This study has determined the optimum digester replenishment frequency so as to ensure that the feed material is fully digested by the time it moves out of the digester, thus minimizing the release of methane to the environment from incompletely digested slurry.

Increase in the amount of substrate fed into the digester is expected to produce more gas, this means a farmer with more substrate is expected to have more gas but only if all the waste is fed into the plant. This study sought to establish the relationship between number of animals that a farmer has plus the quantity of dung fed into a digester, versus the amount of gas produced by that digester.

There are two types of digesters, the batch and the semi-continuous. In batch digesters, the feedstock is fed into the digester once and the plant produces gas over a period until all the materials have been digested after which it is opened and fed again. This means a series of digesters are required so as to have a regular flow of gas from a batch digester (Fulford, 1988). The semi-continuous digester is fed regularly once it has started. This study dealt with fixed dome digesters which are of the semi-continuous type. Therefore the plants are fed at regular intervals and produce gas continuously.

The bacteria require a plentiful supply of nutrients from feed materials, which should contain carbon, nitrogen and inorganic salts in suitable ratios. The ratio of carbon to nitrogen should be about 20-25 carbon to 1 nitrogen (Hankins, 1989). Cow dung has 25:1 carbon/nitrogen which is a good ratio and therefore in this study, nutrient ratio was not expected to affect gas production.

The finer the feed stock, the bigger the surface area for the bacteria to work on and hence the faster the reaction. The plant material in the cow dung has been ground up by the animal teeth and then digested by the animal stomach. Therefore the physical form of cow dung is ideal for the bacteria and the effect of the physical form on gas production was not examined in this study.

Ideally, the age of a plant is not expected to affect the amount of gas produced. However, with time it is expected that there will be accumulation of indigestible and inorganic materials such as lignin and sand in the digester. Such materials may affect gas yield. This study investigated the relationship between the plant ages and biogas production in the various sizes of fixed dome biogas plants.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the procedures used to complete the research. The research design, the area of study, the population, sampling procedure, sample size, data collection instruments and procedure plus data analysis techniques are described.

3.2 Research Design

The study used the case study research method. This is a study which involves a careful and complete observation of a social unit, be that unit a person, a family, an institution, a cultural group or even the entire community (Kothari, 2003). This study method places emphasis on the full analysis of a limited number of events or conditions and their interrelations. The case study is not an experimental research design, as it lacks the concept of manipulation of the independent variable which is one of the characteristics of experimental research (Kothari, 2003; Consuela *et al*, 1984). In this study, instead of manipulating ambient temperature to different levels and then measuring the gas production, the researcher recorded the gas production and temperature in the 52 biogas plants under study. This took place during the range of climatic conditions of the year, which included the hot and dry months of January and February, the cool and wet months of March, April, May and June, and the cold and wet months of July and August. Similarly, the other independent variables, such as plant age and replenishment frequencies, were not set but recorded as observed on the ground.

3.3 Location of the Study Area

The research was planned to take place in Bahati location of the Bahati division, Nakuru North district. However, when the actual geo-referencing was carried out in order to map the selected biogas units, it was found out that some of the biogas plants were situated in the neighbouring Lanet and Dundori locations. These were plants that were not more than 5 Kms from the boundary of Bahati location (Figure 2). Lanet is in the Municipality division of Nakuru district while Dundori is in Dundori Division of Nakuru North District. The name of the study area then, changed from Bahati location to Bahati area. The region is between 5 and

25km north-west of Nakuru town and the extrapolated size from the Government of Kenya GOK (2010) gives an estimated 135.5 km^2 and a total of 16,176 HHs with a human population of 68,075. Lanet is the most populated with a population density of 827 persons/km^2. It is followed by Dundori (443) and lastly Bahati (427). The high population density has resulted in fragmentation of land into small sizes of about 2 acres (0.9 ha) (NDDC, 2003; Lanyasunya *et al*., 2006). The area falls under ecological zone II with an altitude between 1,800 and 2,400m above sea level and an average rainfall of less than 760mm annually. The small sizes of land coupled with the average rainfall makes the area suitable for cattle rearing under the zero grazing system of farming, while the system itself is ideal for biogas production due to the availability of cow dung and the ease at which it is assembled (Mwirigi *et al*., 2009). The dairy animals in the area are predominantly of the Friesian breed with a few Ayrshires. Bull calves are sold for slaughter for dog meat within the first few weeks after birth and as is common with other places of the country that practice the zero-grazing systems of farming, female calves are sold soon after weaning as replacement heifers to other farmers. This is a managerial strategy adopted by farmers to reduce spending scarce feed resources on raising the animals that are not yet productive (Bebe, 2008). The farmers, therefore, had mostly adult cattle that were either in-calf or in milk production. Lanyasunya *et al*., (2006) estimated their weights to be between 345 and 601 kg.

This Location was, therefore, selected for the study due to the following favourable characteristics:

1. A high number of functional fixed dome biogas plants (63 out of 70)
2. Plants of different capacities (8, 10, 12, 16 and 35m^3).
3. Diversity of plant ages of between 1 and 15 years.

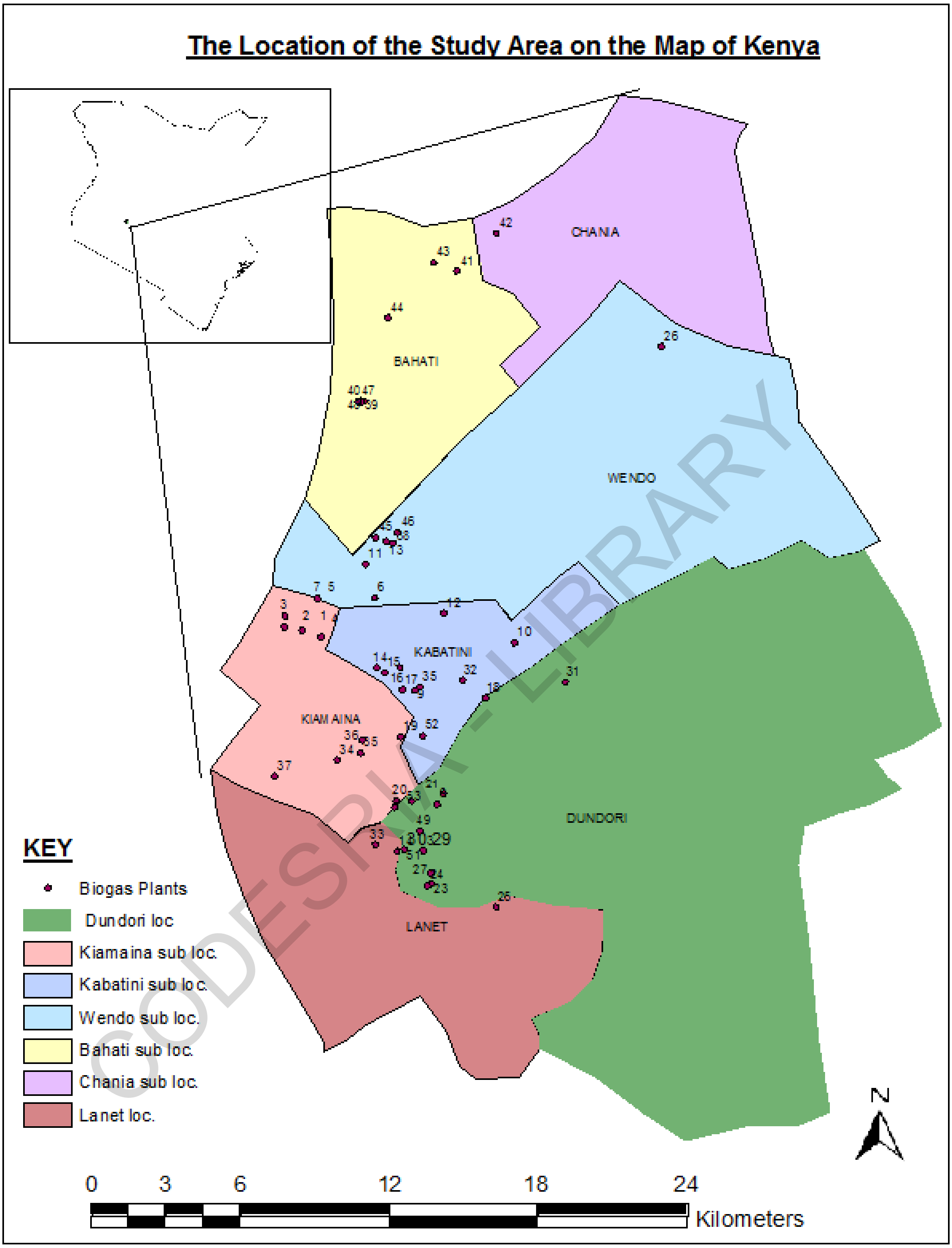


Figure 2: Map of the study area indicating the location of the biogas plants under study

3.4 Population of the Study, Sample Size and Sampling Procedure

According to an earlier research (Mwirigi, 2011), the location had 70 fixed dome plants of which 63 plants (90%) were functional. Although there is no official inventory, this is a very a big number for one administrative location considering that a feasibility study on "promoting biogas systems in Kenya" that was commissioned by the Shell foundation in the year 2007 estimated the number of fixed dome biogas plants across the whole country to be between 300 and 800 plants (ETC, 2007). This is a time when the Country had 71 districts and considering that locations are a fourth level subdivision below provinces, districts and divisions then 63 plants is well above the average for Kenya. Of the 63 plants, 53 were fitted with biogas flow meters for purposes of data collection. Ten plants were not installed with meters and reasons were; 2 HHs were not willing to participate in the exercise, one HH had shifted to another town and nobody remained to use the plant, 2 HHs were not decided whether to participate in the study or not, 2 plants not operational at the time of survey and thus respective HHs could not participate in the research and finally 3 HHs could not be reached for consent to participate in the research even after visiting their homes twice and after leaving behind a workshop invitation and a 'please call me note'. One of the 53 meters failed to operate in the second month, so 52 plants were used for data collection (Figure 2). The spoilt meter was not replaced, as had been projected during the planning stage. This is because the farmer had already shown weariness in taking the readings.

Of the 52 plants, 48 were of the CAMARTEC model, 3 were of the Kenbim type and one was an Akut design. All of them are fixed dome plants with slight differences. The Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) is the model that was being disseminated in Tanzania in the 1980s by a parastatal organization by that name (Mwakaje, 2008). The Akut model was being disseminated in Kenya by the German Technical Cooperation (gtz) in the year 2009/2010 while Kenbim is being promoted in Kenya by the Kenya National Domestic Biogas Program (KENDBIP). Each of the 3 models has a digester which is the main tank and an expansion chamber. The difference between the 3 is that CAMARTEC has a domed digester and a domed expansion chamber while the expansion chambers for the Kenbim and Akut are rectangular and circular respectively. Further, the expansion chambers for the CAMARTEC and Kenbim are covered while that of Akut is not. Figure 3 exhibits the 3 models of the fixed dome biogas plants under study

NO	DESCRIPTION	PHOTO	FEATURES
1	CAMARTEC Biogas plant under construction		• Two domes one is the digester the other one is the expansion chamber. • Fired earth bricks have been used for construction
	Completed CAMARTEC biogas plant		• Only two lids are visible, the one with a pipe is the digester
2	KENBIM Biogas plant under construction		• Domed digester and a square expansion chamber

	Completed KENBIM biogas plant		• Rectangular covered Expansion Chamber • Dome with gas pipe
3	Akut plant under construction		• Circular uncovered expansion chamber • Domed digester
	A completed Akut plant		• A long neck finishing of the dome • Uncovered circular expansion chamber with 4 quandrants

Figure 3: The three models of the fixed dome biogas plant in the study area

3.5 Data Collection and Instrumentation

3.5.1 Primary data collection

Use of Global position system (GPS)

After undergoing an introductory training at the Environmental Research Mapping and Information Systems in Africa (ERMIS) on how to operate a hand held Global Positioning Systems (GPS), mapping of the biogas units was carried out in the month of November 2010 using a Garmin etrex 12 channel GPS. After the survey, some plants that had initially been expected to be in Bahati location was found to be located in the neighbouring Dundori and Lanet locations. It was then concluded that the study area should be redefined from "Bahati Location" to "Bahati area". Figure 2 displays the location of the biogas plants while appendix 2 displays the obtained way points (X and Y co-ordinates) of the plants.

Digester sizes

As seen from Figure 3, the biogas plants have two chambers. The bigger one is the digester, while the smaller unit is the expansion compartment. Digester sizes refer to the bigger chamber and the unit of measure is cubic meters (m^3). Digester size was one of the variables under study and its effect on biogas production was one of the objectives of the study. Sizes of the biogas plants under study were taken at the reconnaissance stage of the research and since the size was not expected to change, the same figure that was recorded during the pre-testing month of November 2010 was carried over to all the data collection period.

Digester ages

Digester ages were taken to mean the number of years that the plant has been in existence. The age of a plant was achieved by subtracting the construction year from 2010 (the survey year) then adding one. For example, for a plant that was constructed in 1996, its age was then calculated as (2010-1996) + 1= 15 years. The age was taken once and kept as the age throughout the study.

Household sizes

The HH size was taken to be the average number of family members in a month including toddlers. The average was an estimate and not a calculation on a day to day basis. This meant that if the HH members up to the 3rd of the month were 2 and thereafter 3, the HH record for that month was taken to be 3 but if the change took place on 17th, then 2 was recorded as the HH size. Effect of HH size on gas production was studied.

Number of cattle

The average number of adult/mature cattle was recorded once in a month. The entries for this information were recorded twice, both in the gas production schedule and the digester feeding form. The purpose of duplication was to improve on reliability, as the farmer could add or subtract an animal and forget to note the same in the gas form which he/she was specifically supposed to complete. On the other hand, the digester feeding form was being completed by the person who fed the digester which in most cases was the cattle attendant who in most cases was an employee. Due to frequent changes of the cattle attendants in some farms, the duplication was necessary. In case a farmer disposed off, or brought in an animal after the recording day for that month, the period that had more days gave the number of animals to be recorded. Recording of the animals followed a procedure similar that of the HH.

Amounts of dung fed into a digester

Farmers collect cow dung and put it in the inlet section of a biogas plant, where they mix it with water, after which they open the inlet for the waste to drain into the digester. The farmers rarely measure how much dung they feed the digester with. In this study, quantification of the amount of dung fed into a digester was introduced. This was achieved through calibration of the tools that the farmers use to replenish the digesters. Standardization of these equipments was carried out during the meter installation stage. Most of the farmers (34) used wheelbarrows, while the rest used buckets with a few of them using a spring balance to weigh the dung. Most of the buckets were estimated to carry 20 kgs of dung when filled to the level mark, while it was estimated that wheelbarrows hold 40 kgs of dung (Table 1). Each farmer recorded the amount of measures he fed his plant and the date of the feeding. At the end of the month, the researcher would add up the number of measures that the plant was fed with the days it was fed. She multiplied the number of measures with the estimated weight of the measure to calculate the amount of dung that was fed into the plant for that month.

Table 1: Utensils Used to Estimate the Weight of Cow Dung Fed to Digesters by the Different Households

No.	Utensil	Estimated weight of dung it holds (kg)	% of Households using that measure
1	Wheelbarrow	40	38.5
2	Wheelbarrow	20	27
3	Bucket	20	11.5
4	Bucket	10	9.6
5	Bucket	6	1.9
6	Bucket	5	1.9
7	Bucket	2.5	1.9
8	Actual weighing		7.7

N=52

Digester replenishment (feeding) frequencies (FF)

Digester replenishment or feeding means collecting cow dung and tipping it into the inlet section of the biogas plant, mixing it with water at a ratio of 1:1 (weight/volume of cow dung vs. water), sorting out to remove dirt such as stones and pieces of feed and then stirring the mixture, followed by opening the inlet lock to allow the mixture to drain into the digester. The feeding frequency thus referred to the number of days that the above exercise was carried out in a month. The assumption was that each farmer fed the digester once in a day. Each farmer marked with a tick (√), each day of the month that he fed the digester. (Appendix 3) displays this record. The FF was then categorized into 7 ordinal categories which for ease of calculation were further computed into numbers so as to give numerical figures and thus a scale type of measure (Table 2).

Table 2: Feeding Frequencies/Categorization

Category No	Number of days fed /Category	Scale computation
1	0	0
2	1-5	1
3	6-10	2
4	11-15	3
5	16-20	4
6	21-24	5
7	>25	6

Gas meter readings

Gas meters were imported from China and used to record the amount of gas used by a HH. The meters had a maximum and minimum flow rate of 1.6 and 0.016 m^3/h respectively. They have an operating pressure range of between 0.5 and 15 kpa and the maximum index reading is 99999.99 m^3. The operating ambient temperature and relative humidity are -20~+50°C and 98% (30 °C) respectively. They have a service life of 10 years. Data from gas meters as well as the replenishment frequencies was collected by a HH member who was recruited and trained on how to record the information. The criteria for selecting the HH member included literacy levels, willingness to do the work and availability, as well as permission from the HH head.

Gas meter readings were taken once daily after making the last meal for the day or early in the morning before making any meal. The choice of recording time depended on whether the meter was installed outside the house or inside. For farmers whose meters were outside, they took the readings in the morning due to insecurity of going out at night. The majority of the famers (46) took records of their meters in the evening after cooking. The recording forms were calendar months, with spaces for gas meter recordings for each day of the month. The forms were issued in advance for each month. The monthly data was collected in the ensuing month by the research team (researcher plus 2 assistants). The team would then check the data to ensure that all the entries had been made. They would then take the meter reading for that day and compare it with the last reading on the form. This was for purposes of triangulating the provided information. They would further countercheck from their monthly data summary for the previous month for a change in the amount of gas used that is either a rise or reduction. In case of a significant change, they would then pose the detailed questions to the farmer as displayed in Appendix 4.

In some of the questions, the farmers did not have answers and this forced the research team to carry out an exploration of the biogas unit and its surroundings. One such case was a farmer with only one cow, having the same size of plant as others with one cow, was producing more gas than farmers with 2 cows. The farmer in question was also feeding less dung into the plant compared to other farmers. The farmer had no answer to question 3 on why their plants produce more gas than others of the same size, make and feeding amount and frequency. On exploration of the biogas plant and its environs, it was discovered that an overflow of washings from her poultry unit had found its way to the zero grazing unit. The overflow joined the washings from the cattle shed into the biogas unit. In addition, urine from the cow shed was also draining to the biogas unit (this was not common in most farms). The two extra sources of organic matter thus led to the higher production of gas. Although the data in Appendix 4 was not used for quantification, it did help generate and clarify dimensions present in the study.

The form collection process was repeated until forms for all the pre-testing months and the study periods were collected. In February 2011, forms for January were collected and so on until the forms for August were collected in September. At the end of the month, the researcher would calculate the amount of gas used by the HH for that month by subtracting the first day's record from that of the last day. The figure would then be recorded on the same form in terms of cubic meters (m^3) of gas. Appendix 5 displays the gas recording form for meter No. 46 for May while Appendix 6 displays an installed meter and a meter screen displaying a reading. The data that is used for analysis is for January to August 2011. However, 3 meters had not been fitted with meters by January 10th and to fill in the information for those days, the series mean imputation method of replacing missing values with the mean for the entire series was used as in the Statistical Package for Social Sciences (SPSS, 2009). The series data used in the current study is that for January for each of the farmers in question.

Formatted forms

Two schedules (Appendix 3 and 5) were used to record information on digester sizes and ages, HH sizes, number of cattle owned by a HH, the amount of dung fed into a digester and the days that it was fed.

3.5.2 Secondary data collection

Secondary data was collected by the researcher throughout the course of the research from sources such as constructors and promoters of biogas plants, government ministries and institutions, such as the Ministry of Livestock Development and National Environmental Management authority (NEMA), books, newspapers, journals and electronic media. The sought information included parameters such as the sizes and construction dates of the biogas plants and other aspects of the technology that relate to the CDM.

The meteorological weather station located in Lanet (Latitude 0-16'S Longitude 36' 06E) of the municipality division in Nakuru district and whose area of coverage includes the study area, provided the monthly weather data. The data included the daily maximum, mean and minimum temperatures. It also included the monthly maximum, minimum and mean temperatures. The latter was used for analysis in the current study. Daily and total monthly rainfall was also obtained. Appendix 7 displays one such form.

3.6 Data Analysis

The collected data was analyzed by use of descriptive (means, frequencies and percentages, standard deviations (SD)) plus inferential statistics using the SPSS software version 17. The statistical procedures used in inferential statistics included correlation coefficients, stepwise multiple regression and analysis of variance (ANOVA). Correlation analysis was used to select the most important independent variables contributing to the dependent variable; regression analysis was used to determine the predictors of the dependent variable on the basis of statistical criteria. The stepwise multiple regression analysis listed the independent variables in the order in which they explain the significant proportion of the variance in the equation, starting with the best. The ANOVA was used to find out if the difference in the gas production between the months was significant, an effect which was assumed could only be caused by the climatic variations. The stepwise multiple regression was therefore carried out on 6 of the 7 variables, namely the plant size and age, the HH size, the number of cattle owned by the HH, the amount of dung fed into the plants and the frequency at which it was fed. The six variables have been grouped in this way because different values have been generated by each biogas plant owning HH. By contrast, ambient temperature was the same for all HHs for any given day or month, so it was excluded from the above list. ANOVA was, therefore, used to analyze ambient temperature separately from the other six variables under study. The regression analysis and the ANOVA guided the researcher in exploring “the effect of the independent variables on gas production (dependent variable)”. The data analysis chart is shown in Table 3.

Table 3: Data Analysis Table

Questions	INDEPENDENT VARIABLE	DEPENDENT VARIABLE	STATISTICS
Q1: How much gas do the various sizes of fixed dome biogas plants produce?	**Plant Sizes** -35 m^3 -16m^{3s} -12 m^3 -10m^3 -8m^3	Amount of biogas produced (m^3)	-Descriptive (Means, frequencies, SD)
Q2: What are the effects of the following factors on the amount of biogas produced by the fixed dome biogas plants? I. Plant size II. plant age III. Household size IV. Number of cattle V. Amount of dung VI. plant replenishment frequency VII. Ambient Temperature	**I. Plant Sizes** 35 m^3 -16m^3 -12 m^3 -10m^3 -8m^3	Amount of biogas produced (m^3)	-Correlation Coefficient -Stepwise Multiple Regression
	II. Plant ages Between 1 and 15 years	Amount of biogas produced (m^3)	-Descriptive (Means, frequencies, SD) -Correlation Coefficient -Stepwise Multiple Regression
	III. Household size (number)	Amount of biogas produced (m^3)	-Descriptive (Means, frequencies, SD) -Correlation Coefficient -Stepwise Multiple Regression
	IV. Number of cattle	Amount of biogas produced (m^3)	-Descriptive (Means, frequencies, SD) -Correlation Coefficient -Stepwise Multiple Regression
	V. Amount of dung fed into a digester (kg)	Amount of biogas produced (m^3)	-Descriptive (Means, frequencies, SD) -Correlation Coefficient -Stepwise Multiple Regression
	VI. Replenishment frequency (Days in a month) 0 1-5 6-10 11-15 16-20 21-25 ≥25	Amount of biogas produced (m^3)	-Descriptive (Means, frequencies, SD) -Correlation Coefficient -Stepwise Multiple Regression
	VII. Ambient temperature Mean Monthly Temperature (^{0}C)	Amount of biogas produced (m^3)	-Descriptive (Means, frequencies, SD) -ANOVA

CHAPTER FOUR

RESULTS

4.1 Introduction

The first section of this chapter presents the results of the descriptive data analysis on both the independent variables (plant sizes and ages, HH sizes, amount of cow dung fed into the digester size, plant replenishment frequency and finally the ambient temperature) and the dependent variable (gas production). The section ends up by answering the first study question on the amount of gas produced by the different sizes of biogas plants in the study area. The last section presents the results of the inferential analysis that help to answer the second study question on the effects of the 7 independent variables on the dependent variable.

4.2 Descriptive Results

The descriptive information presented in this section includes; distribution (frequencies at which values recur), central tendencies (means, modes and medians) and dispersion (range and standard deviation) of the independent and dependent variables.

4.2.1 Sizes of the biogas plants

There were five sizes of biogas plants ranging between 8 m^3 and 35 m^3. The majority of the plants (71%) were 16 $m^{3,}$ While cumulatively, 98 % of the plants were between 8 and 16 m^3 (Table 4).

Table 4: Sizes of the 52 Biogas Plants

Size (m3)	Frequency	Percent (%)	Cumulative %
8	2	4	4
10	10	19	23
12	2	4	27
16	37	71	98
35	1	2	100

N=52

4.2.2 Ages of the biogas plants

The oldest plant was 15 years old and the youngest was 1 year old (Table 5). The $16m^3$ (S16) were the first ones to be constructed over a period of 11 years (Figure 4). However, in the last 4 years prior to the study, smaller plant sizes were most frequently installed.

Table 5: Plant Ages

Age (yrs)	Frequency	Percent (%)	Cumulative %
1	4	8	8
2	6	12	20
3	8	15	35
4	6	12	46
5	1	2	48
7	1	2	50
8	5	10	60
9	4	8	68
10	10	19	86
11	1	2	88
12	3	6	94
13	2	4	98
15	1	2	100

N=52

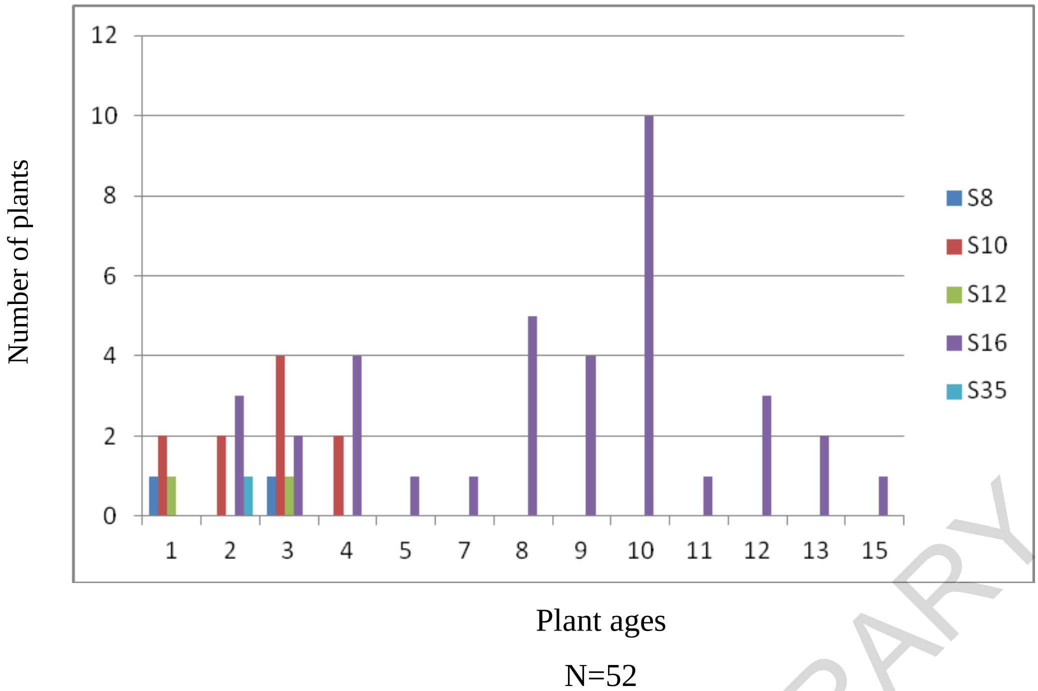


Figure 4: Ages of the various sizes of plants

4.2.3 Household (HH) sizes

Generally, the range of HH sizes over the study period was between 1 and 14 persons. Over 75% of the HHs had between 2 and 6 members for any given month. On average from all the plant sizes, one person was recorded as the least number of persons in a HH for all the months, except February and March when 2 was the lowest number of documented HH members. On the upper limit, January to April had 10 as the highest number of members in a home, while 14 was the maximum number of people in a family in the rest of the months. The mean number of family members was 4 for all the months except August whose mean was 5. The mode was 4 for all the months except for May and June when it was 3. Multiple modes of 3 and 4 existed in August. On average, the HH with S12 plants had fewer family members than the others, while the family with S35 plant recorded the highest number of people per month throughout the study period. Table 6 displays the percentage of HHs for each of the HH size over the study period while Table 7 shows the HH size per set of digester size.

Table 6: Percentage of HHs for each of the HH Size over the Study Period

HH Size	% of Households/month							
	January	February	March	April	May	June	July	August
1	2	0	0	2	2	2	2	4
2	17	15	12	17	19	17	14	17
3	17	23	29	21	25	25	21	19
4	31	27	31	27	23	17	27	19
5	17	21	12	12	19	23	17	8
6	8	8	10	10	8	8	6	14
7	4	2	4	6	2	4	8	8
8	2	2	2	2	0	0	2	4
10	2	2	2	2	0	2	0	4
12	0	0	0	0	0	0	2	2
14	0	0	0	0	2	2	2	2
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

N=52

Table 7: HH Members per Set of Digester Size

Digester Sizes	N	Statistics	Households/Month							
			January	February	March	April	May	June	July	August
8	2	Mean	4	4	3	4	4	4	4	7
		Minimum	3	3	3	3	3	3	3	3
		Maximum	4	5	3	5	5	5	5	10
10	10	Mean	4	4	4	5	4	4	4	5
		Minimum	2	2	2	2	2	2	2	3
		Maximum	8	5	5	10	5	10	8	10
12	2	Mean	2	3	3	4	4	4	3	4
		Minimum	2	2	2	2	2	2	1	1
		Maximum	2	3	4	5	5	5	5	6
16	37	Mean	4	4	4	4	4	4	4	4
		Minimum	1	2	2	1	1	1	2	1
		Maximum	7	8	8	8	7	7	12	12
35	1	Mean	10	10	10	10	14	14	14	14
		Minimum	10	10	10	10	14	14	14	14
		Maximum	10	10	10	10	14	14	14	14
Total	52	Mean	4	4	4	4	4	4	4	5
		Minimum	1	2	2	1	1	1	1	1
		Maximum	10	10	10	10	14	14	14	14

4.2.4 No of cattle

Although the number of cattle per HH varied between 0 and 27, most of the farmers (46-56%) owned between 2 and 3 cows. One farmer had no cattle and she used waste from her neighbor's cattle as the neighbor had no biogas unit. Two farmers, one who had 1 cow and the other farmer who had 2 cows, each lost 1 cow in June. Subsequently, the farmer who had had 2 cows lost his second in July. During the period when they had no animals, they either did not feed the plants or they borrowed cow dung from their neighbors. Overall, the range of the total number of animals owned by the farmers in the study period varied between 187 and

193. The mean number of cattle was 4 for January to July and 5 for August, while the mode was 3 for January to July and 2 for August. On a plant size basis, the mean number of cattle for the S8, S10, S12 and S16 was roughly 3, while that of S35 was 27. Table 8 displays the percentage of HHs that owned a certain number of animals and Table 9 shows the cattle distribution by sets of plant sizes.

Table 8: Percentage of Cattle Owned by the HHs over the Study Period

No. of Cattle	% 0f Households/month							
	January	February	March	April	May	June	July	August
0	2	2	2	2	2	4	6	6
1	10	10	8	8	8	8	10	8
2	23	23	25	25	23	25	21	25
3	31	31	31	31	29	27	27	21
4	14	14	14	14	15	12	10	14
5	12	12	12	10	12	14	15	14
6	6	6	6	8	8	8	8	8
7	2	2	2	2	2	2	0	2
9	0	0	0	0	0	0	2	2
27	2	2	2	2	2	2	2	2
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

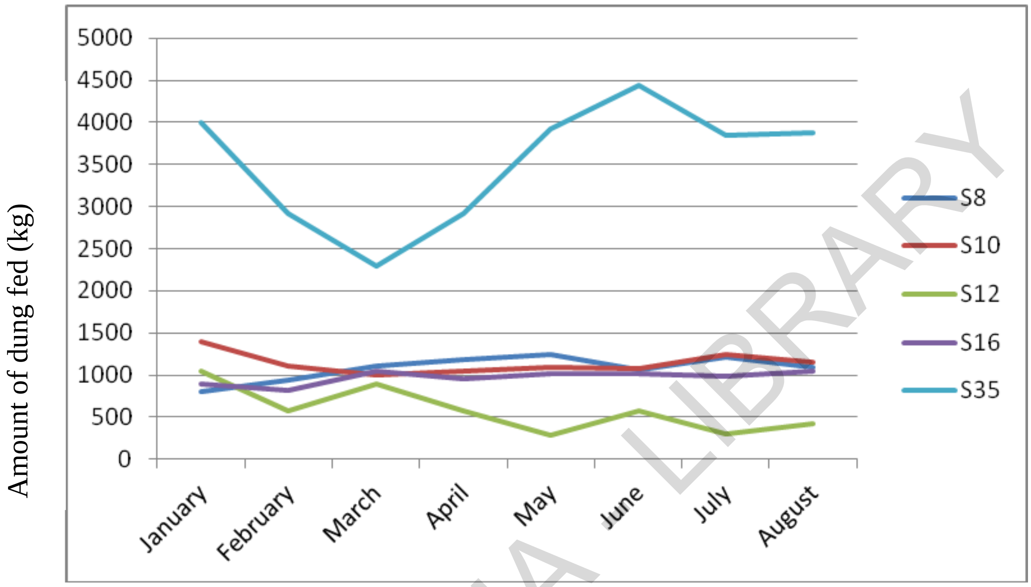
N=52

Table 9: Cattle Distribution per Set of Plant Sizes

Digester Size (m^3)	N	Statistics	Cattle/month							
			January	February	March	April	May	June	July	August
8	2	Sum	5	5	5	5	5	5	5	5
		Mean	3	3	3	3	3	3	3	3
		Minimum	2	2	2	2	2	2	2	2
		Maximum	3	3	3	3	3	3	3	3
10	10	Sum	33	33	33	33	33	33	33	33
		Mean	3	3	3	3	3	3	3	3
		Minimum	2	2	2	2	2	2	2	2
		Maximum	6	6	6	6	6	6	6	6
12	2	Sum	6	6	6	6	6	6	6	5
		Mean	3	3	3	3	3	3	3	3
		Minimum	3	3	3	3	3	3	3	2
		Maximum	3	3	3	3	3	3	3	3
16	37	Sum	116	116	117	118	122	120	118	123
		Mean	3	3	3	3	3	3	3	3
		Minimum	0	0	0	0	0	0	0	0
		Maximum	7	7	7	7	7	9	9	9
35	1	Sum	27	27	27	27	27	27	27	27
		Mean	27	27	27	27	27	27	27	27
		Minimum	27	27	27	27	27	27	27	27
		Maximum	27	27	27	27	27	27	27	27
Total	52	Sum	187	187	188	189	193	191	189	193
		Mean	4	4	4	4	4	4	4	4
		Minimum	0	0	0	0	0	0	0	0
		Maximum	27	27	27	27	27	27	27	27

4.2.5 Amount of dung fed

Overall and with an exception of the S35, an average of 1,000 kgs of dung was fed into each of the plant sizes in each of the 8 months under study. However, some individual plants, some were not fed in some months while others were fed with as much as 5,000 kg of dung. Figure 5 and Table 10 display the amount of cattle waste fed into the various sets of digester sizes.



N= 52

Figure 5: Mean amount of dung fed per set of digester size

Table 10: Amount of Dung (kgs) Fed in to Each Set of Plant Sizes

Digester Size	N	Statistics	Dung Fed (kgs)							
			January	February	March	April	May	June	July	August
8	2	Mean	807.00	935.00	1110.00	1185.00	1240.00	1065.00	1220.00	1090.00
		Std. Deviation	264.46	134.35	127.28	63.64	28.28	190.92	28.28	212.13
10	10	Mean	1398.90	1112.90	993.80	1043.80	1090.50	1071.30	1249.40	1154.60
		Std. Deviation	728.48	639.86	559.44	445.54	471.60	551.92	789.77	629.19
12	2	Mean	1050.00	570.00	899.00	580.00	280.00	580.00	300.00	420.00
		Std. Deviation	212.13	325.27	482.25	367.70	395.98	367.69	424.26	593.97
16	37	Mean	889.27	814.78	1042.19	959.08	1008.76	1010.51	982.32	1044.30
		Std. Deviation	676.03	708.86	745.67	678.45	846.09	890.91	911.31	1026.21
35	1	Mean	4000.00	2920.00	2300.00	2920.00	3920.00	4440.00	3840.00	3880.00
		Std. Deviation	.	.	.	.	.	.	.	.
Total	52	Mean	1050.12	907.81	1054.17	1007.19	1061.33	1073.69	1071.54	1097.79
		Std. Deviation	796.29	726.49	696.36	666.90	857.47	923.06	941.44	996.76

4.2.6 Digester feeding frequencies (FF)

The FF was calculated (refer to Table 2) as 0, 1 for 1-5 and so on up to 6 for FF greater than 25(>25). A farmer with a FF of 1-5 fed his/her plant 1 to 5 days in a calendar month. Overall, the majority of the farmers either fed their digesters 1-5 days in a month (17-33%) or more than 25 days in a month (21-40%). This translates to once a week and once daily for the two feeding regimes respectively (Table 11). However, S8 plant owners used the >25 days feeding regime in most of the months while the S12 plant owners used the 0 or 1-5 plant feeding frequency in most of the months (Table 11).

Table 11: Percentage of HH who practiced Certain Digester Feeding Frequencies (FF)

Feeding Frequency (FF)	Computed Score	% of Households/month							
		January	February	March	April	May	June	July	August
0	0	0	12	0	2	4	4	8	8
1-5	1	29	17	19	25	33	27	27	25
6-10	2	14	12	15	15	4	12	4	10
11-15	3	12	12	14	8	12	14	8	10
16-20	4	6	2	10	6	2	4	10	6
21-25	5	19	17	2	8	14	4	14	4
>25	6	21	27	40	37	33	37	31	37
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

N=52

Table 12: FF per Set of Plant Size

Digester Size/N	N	Statistics	No. of Feeding days/score/month							
			January	February	March	April	May	June	July	August
S8	2	Minimum	21-25	>25	>25	>25	>25	11-15	21-25	>25
		Maximum	>25	>25	>25	>25	>25	>25	>25	>25
		Mean score	6	6	6	6	6	5	6	6
S10	10	Minimum	1-5	1-5	6-10	1-5	1-5	1-5	1-5	1-5
		Maximum	21-25	21-25	21-25	21-25	21-25	21-25	21-25	21-25
		Mean score	4	4	5	4	4	4	4	5
S12	2	Minimum	1-5	1-5	1-5	6-10	0	6-10	0	0
		Maximum	>25	6-10	>25	6-10	1-5	6-10	1-5	1-5
		Mean score	4	2	4	2	1	2	1	1
S16	37	Minimum	1-5	0	0	1-5	0	0	0	0
		Maximum	>25	>25	>25	>25	>25	>25	>25	>25
		Mean score	3	3	3	3	3	3	3	3
S35	1	Minimum	1-5	11-15	16-20	16-20	21-25	21-25	21-25	>25
		Maximum	1-5	11-15	16-20	16-20	21-25	21-25	21-25	>25
		Mean score	1	3	4	4	5	5	5	6

4.2.7 Ambient temperature (^{O}C)

The daily minimum ambient temperatures were between 7 and 10.6, while the range for the maximum was 26.6-31.4 (Table 13). The average mean monthly ambient temperatures varied between 18.2 and 20.5 thus a 2.5 ^{O}C difference between minimum and maximum. The hottest month was March, while the coldest was August (Figure 6). January and February were the driest months, while July was the wettest (Figure 7). Appendix 7 displays the detailed weather report for the month of August.

Table 13: Weather Summary for the Study Period

Month	Max Rec (daily)	Min Rec (daily)	Max Mean (Monthly)	Min Mean (monthly)	Average Mean (monthly)	Rain Days	Total Rain mm	Highest Rec	Min Rec	Daily Mean
January	30	7	28.2	10.7	19.5	1	1.1			
February	30.8	7.6	29.2	11.8	20.2	2	2.2			
March	31.4	9.8	28.4	12.6	20.5	10	104.5	24.4	0	3.4
April	29.7	10.6	26.6	12.3	19.5	11	58.4	25	0	2.3
May	27.9	10.2	25.4	12.6	19	11	111.1	27	0	3.8
June	27.1	10	24.8	13.1	19	18	109	20.6	0	3.6
July	27.2	10.2	24.7	11.8	18.3	19	173	29.2	0	5.8
August	26.5	9.6	23.8	12.6	18.2	16	123	26	0	4.6

Note: Max (Maximum), Min (minimum), Rec (Record)

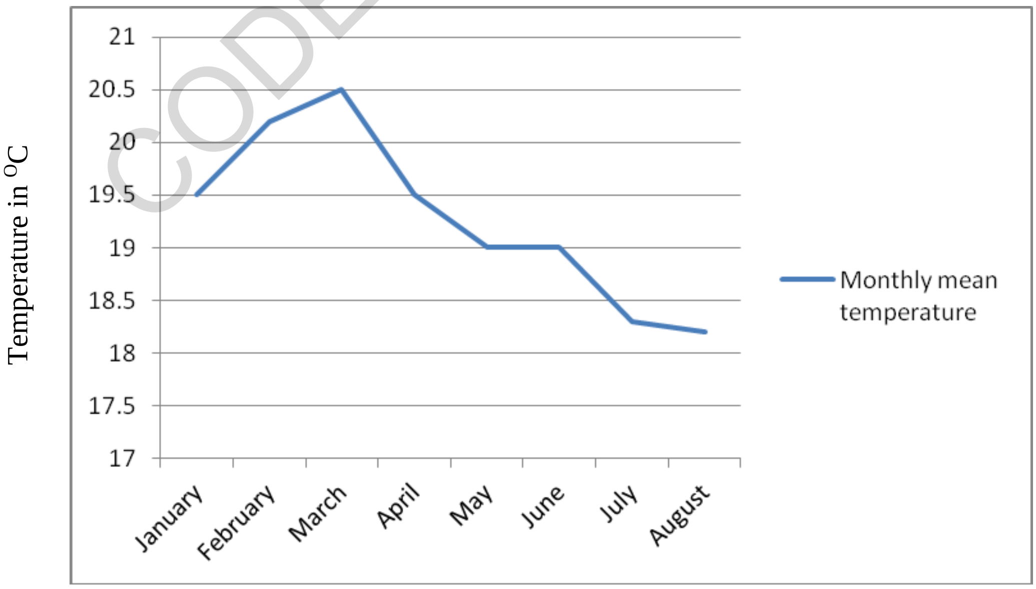


Figure 6: Average mean monthly ambient temperatures (OC)

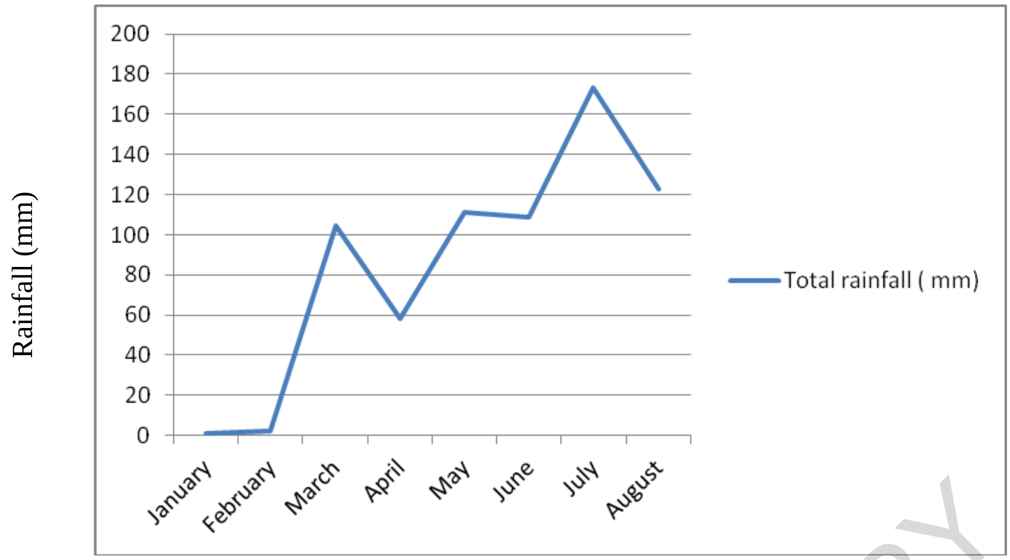


Figure 7: Rainfall (mm)

4.2.8 Gas production by the various sizes of fixed dome biogas plants

Of the 5 sizes of biogas plants under study, the biggest size (S35) produced the higest amount of gas. This was in the range of 177 and 424 m^3 of gas per month with a mean of 331 m^3. This was unexpectedly followed by the smallest size (S8), with the mean monthly gas production lying between 53 and 88.5 m^3 over the study period. The lowest producers were the S12 sizes while all the plants combined produced an average 3,096 m^3 of gas monthly with a mean of 60 m^3 and a standard deviation of 49. Figure 8 and Table 14 display the mean monthly gas production by the various plants sizes.

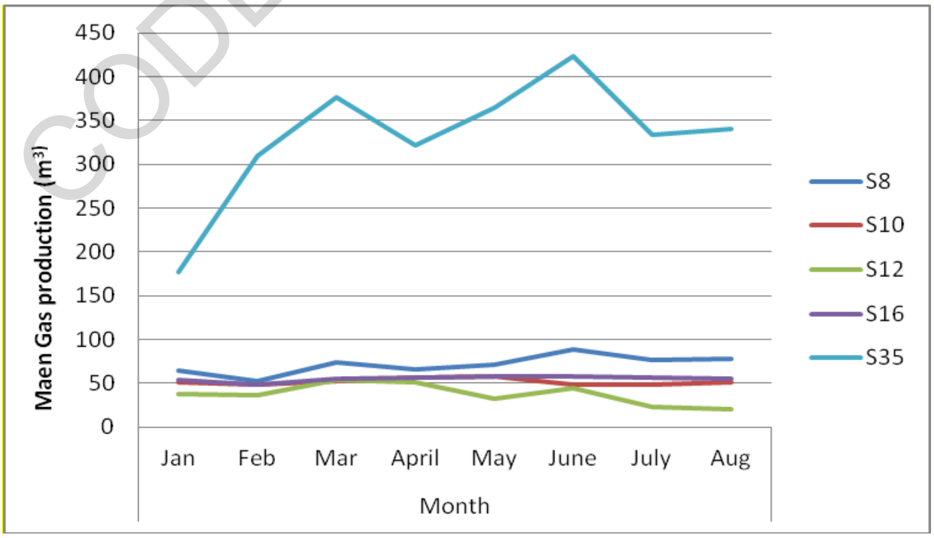


Figure 8: Mean gas production by the various plant sizes

Table 14: The Mean Gas Production by the various sizes of biogas plants over the study period

Digester size (m^3)	N	Mean (m^3)	Std. Deviation
8	2	72	15
10	10	52	20
12	2	37	31
16	37	55	33
35	1	331	.
Total	**52**	**60**	**49**

4.3 Inferential Results

Three types of inferential procedures were used in this study. These are Correlation, Stepwise Multiple Regression Analysis and Analysis of Variance (ANOVA) as described in section 3.6.

4.3.1 Correlation between the dependent and independent variables

Table 15 displays the correlation analysis matrix for 6 of the 7 independent variables under study (plant size and age, HH size, number of cattle, amount of cow dung and feeding frequency) versus the dependent variable (gas production) and the data gives an insight to the various bivariate relationships. The correlation coefficients on the diagonal top left to bottom right in the matrix are 1.000. This means that each variable has a perfect linear relationship with itself and correlations below the same diagonal in the matrix are a mirror image of those above.

Table 15 : Correlation Matrix for the 6 of the 7 Variables under Study

Variables		Gas Production	Digester Size	Digester Age	HH Size	Cattle	Dung Fed	FF
Gas Production	r	1.000						
Digester Size	r	.57	1.000					
Digester Age	r	-.26	.32	1.000				
HH Size	r	.71	.47	-.22	1.000			
Cattle	r	.87	.65	-.13	.50	1.000		
Dung Fed	r	.82	.29	-.21	.47	.65	1.000	
FF	r	.33	-.14	-.29	.11	.31	.45	1.000

N=52

4.3.1.1: Digester size and gas production

The range of digester sizes in the study area was between 8 and 35 m^3 (refer to Table 4). The relationship between the digester size and gas production is strong, with a Pearson correlation coefficient (r) of 0.57 and a significance level of 0.000 ($p < 0.001$). This means that gas production increases with biogas plant size and vice versa. A scattergram of the relationship between digester size and gas production was examined. There was no evidence of curvilinear or undue influence of outliers (Figure 9).

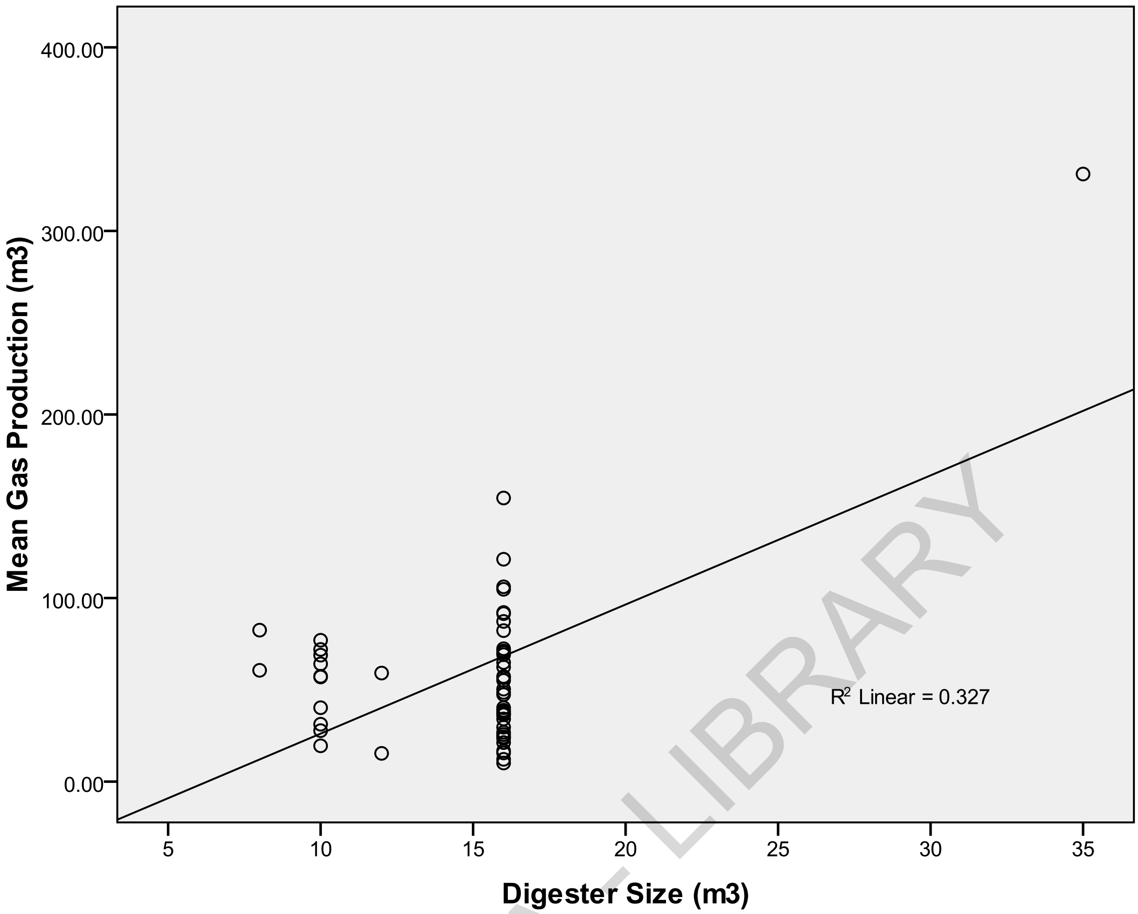


Figure 9: The scatterplot and the bivariate regression line between digester size and gas production

4.3.1.2 : Plant age and gas production

The plant ages varied between 1 and 15 years (refer to Table 5). The relationship between the plant age and gas production had a Pearson correlation of -0.26 and a significance level of 0.30 ($p<0.05$), indicating a statistical insignificant relationship. However, the negative sign in the relationship indicates that plant age reduces gas production though not at a statistically significant level. A scattergram of the relationship between the digester age and gas production confirms the negative relationship with the regression line moving from upper left to lower right as Figure 10 indicates.

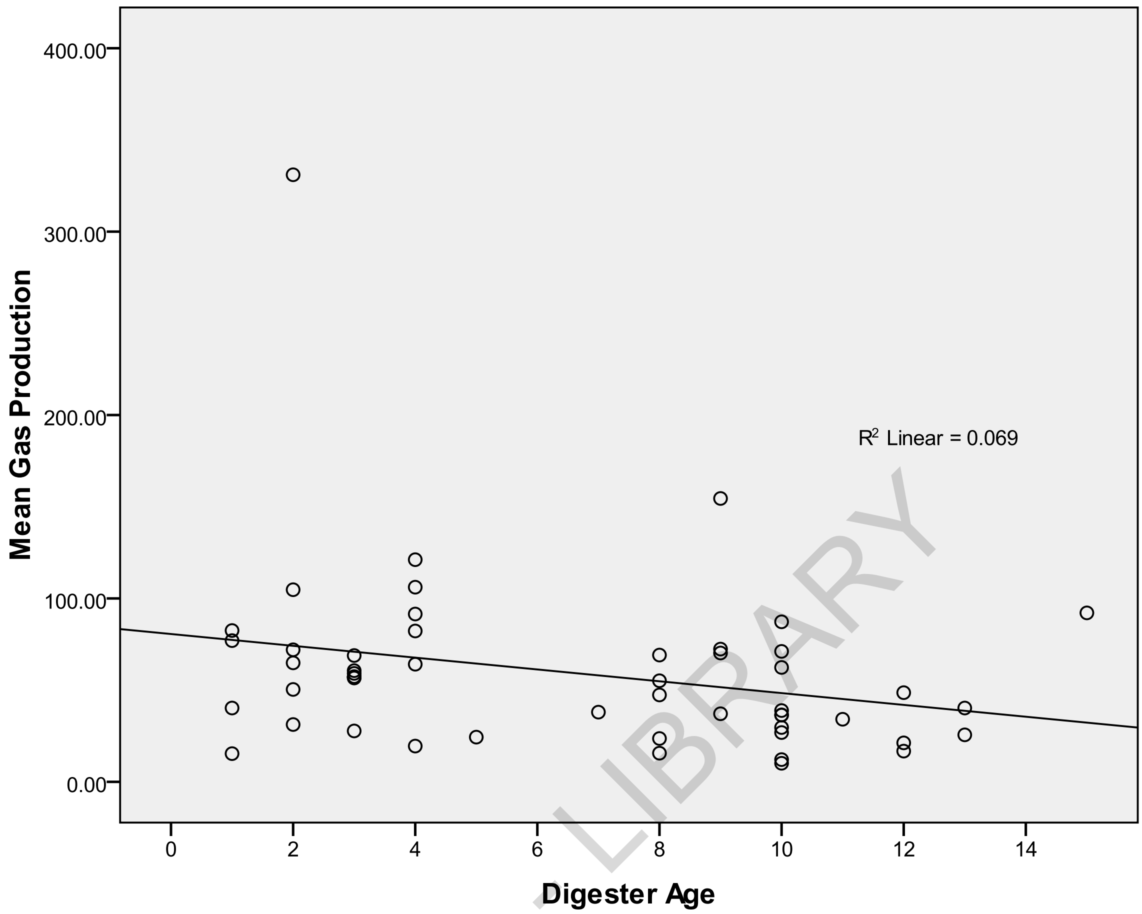


Figure 10: The scatterplot and the bivariate regression line between digester age and gas production

4.3.1.3: Household (HH) and gas production

The HH sizes were between 1 and 14 (refer to Table 6). The relationship between the HH size and gas production was found to be strong with a Pearson correlation coefficient of 0.71 and a significance level of 0.000 ($p < 0.001$), indicating a statistically significant relationship. This means that the larger the HH size, the more gas was produced by their plant. The scattergram of the relationship between the HH and gas production (Figure 11) confirmed this linear relationship.

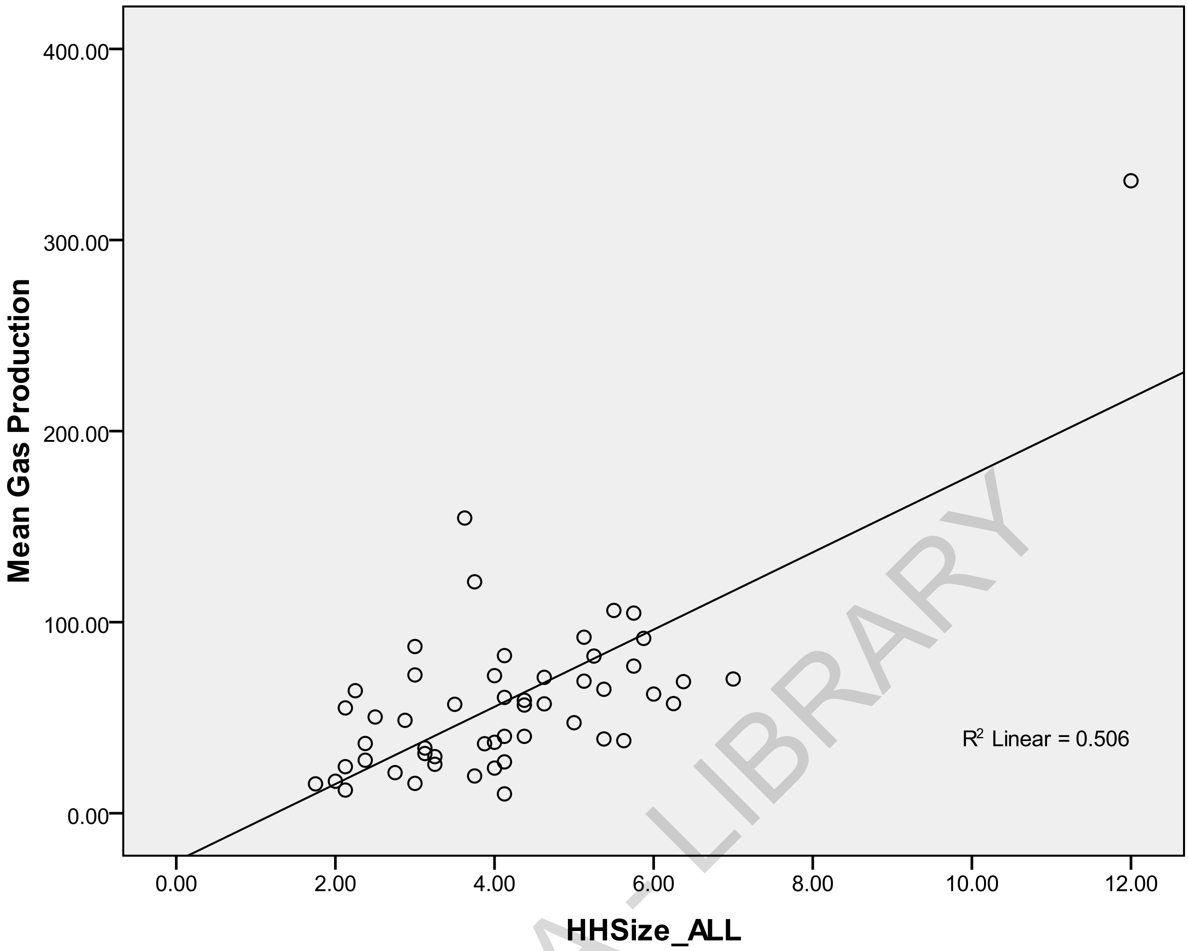


Figure 11: The scatterplot and bivariate regression line of the relationship between the HH size and gas production

4.3.1.4: Number of cattle per HH and gas production

The majority of farmers had between 2 and 3 cattle, while the range was between 0 and 27 (refer to Table 8). The relationship between the number of cattle and gas production had a strong correlation coefficient of 0.87 and statistically significant level of 0.000(p< 0.001). Thus an increase in number of cattle leads to increased gas production by a plant. A scattergram of the relationship between the numbers of cattle per HH, versus gas production puts the slope of the scatter on a straight line (Figure 12).

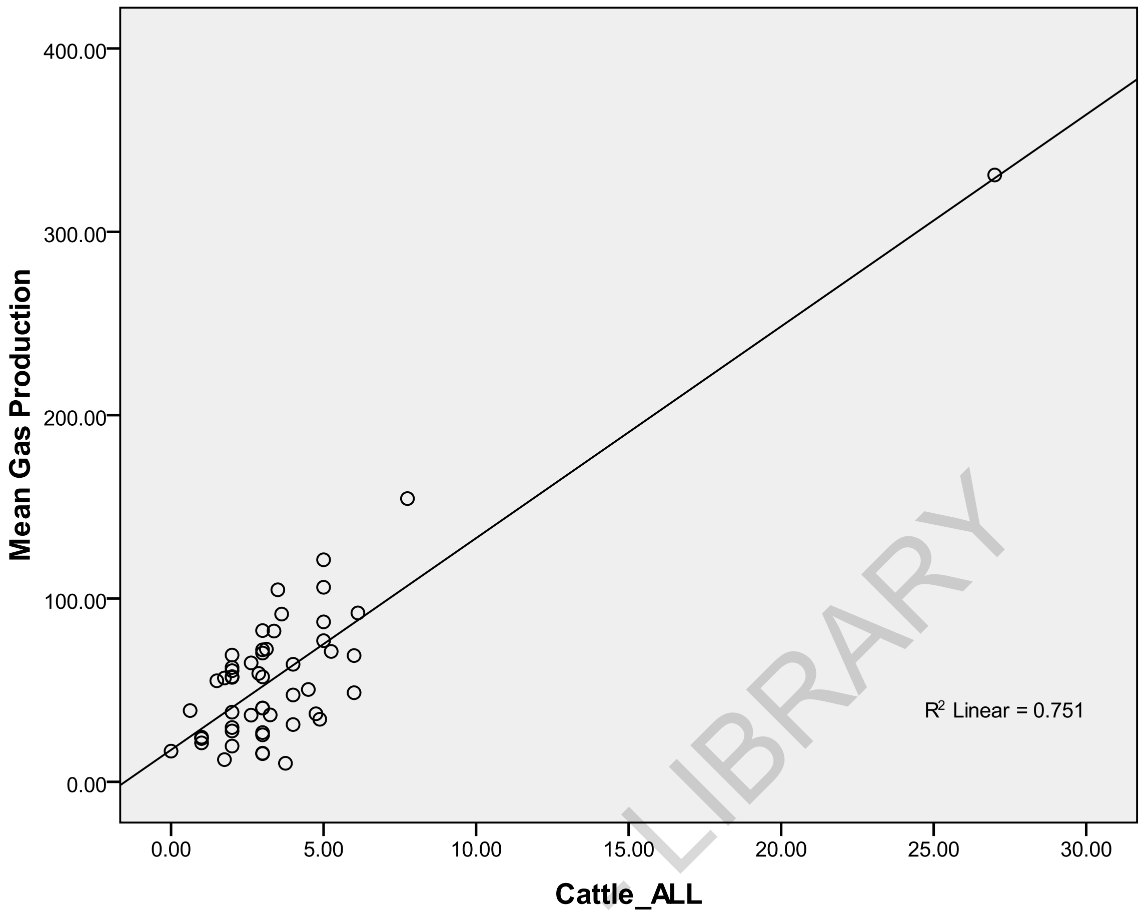


Figure 12: The scatterplot and bivariate regression line of the relationship between the numbers of cattle per HH vs. gas production

4.3.1.5: Dung fed into a plant and gas production

The average amount of cattle dung fed into each plant under study in a given month was approx 1,000 kgs (see Table 10). There was a strong relationship between dung fed into a plant and the amount of gas produced by that plant, as indicated by a Pearson correlation of 0.82 and statistical significance level of 0.000 ($p<0.001$). This means that the more dung that was fed into a plant, the more gas it produced. Figure 13 displays a linear relationship between the amount of dung fed into a plant and gas production.

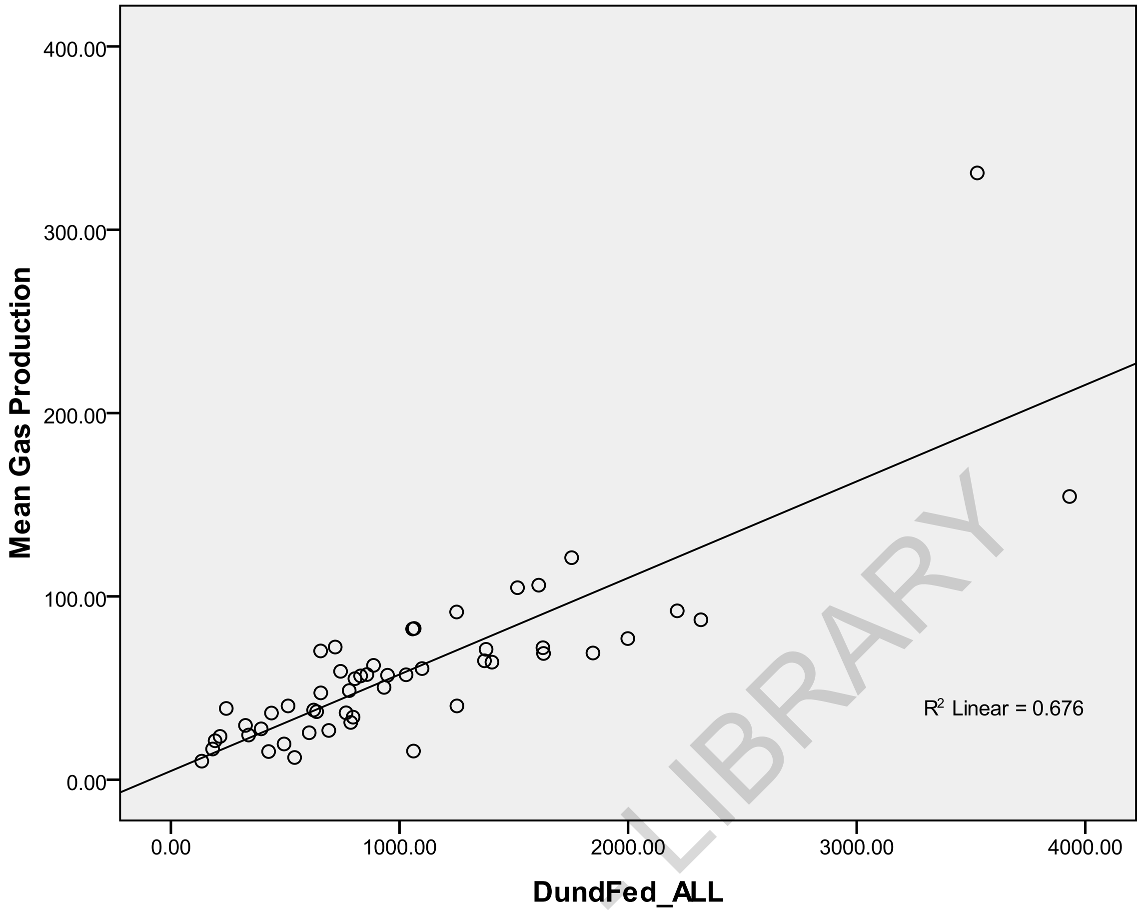


Figure 13: The scatterplot and bivariate regression line of the relationship between the amounts of dung fed into a digester vs. gas production

4.3.1.6: Feeding Frequency and gas production

Most of the farmers either fed their plants once a week or daily. The relationship between the digester feeding frequency and gas production had a weak Pearson correlation coefficient of 0.33 and a statistical significance level of 0.009 ($p<0.001$). This is an indication that although the feeding frequency has some effect on gas production, the relationship was not statistically significant. Figure 14 displays the scatterplot and the bivariate relationship on the same.

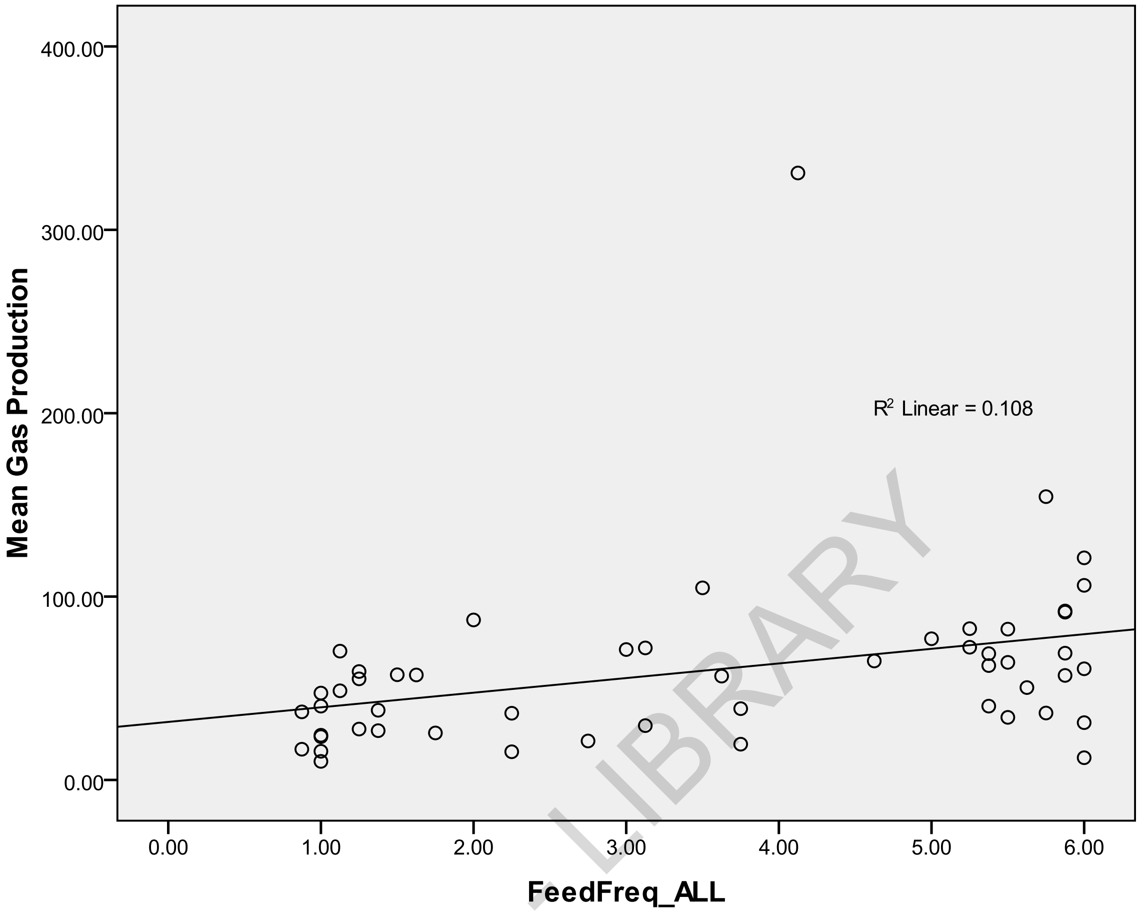


Figure 14: The scatterplot and bivariate regression line of the relationship between the digester feeding frequency vs. gas production

4.3.2 Regression analysis

Table 16 displays the values Multiple R, R square and R square change, B, Beta and t from the multiple regression analysis. Multiple R is the correlation coefficient, R square is the multiple correlation coefficients squared and when multiplied by 100 it gives an indication of the cumulative percentage contribution of the predictor to the dependent variable (Howitt and Cramer, 2003). R square change when multiplied by a 100 gives the percent contribution of each independent variable to the dependent variable. B is the unstandardized regression coefficient or the slope of the regression. This means that from every increase of 1.00 on the horizontal axis, the score on the vertical axis changes by the value of B. Beta is the standardized regression coefficient.

In the current study, the stepwise multiple regression analysis indicate that the number of cattle owned by a HH was entered first and explained 75% of the variance of gas production ($F_{1.50}$=158.48, p<0.001). Dung fed into a digester was entered second and explained a further 10% ($F_{1.49}$=33.24, p<0.001). Lastly, the HH was listed and it contributed 4% to the variance of gas production ($F_{1.48}$=15.65, p<0.001). This means that an increase in gas production is associated with an increase in number of animals, dung fed and HH thus the 3 variables accounts for a total of 89% effect on gas production by a digester. These assisted in answering the questions; "What effects do the HH sizes, number of cattle owned by a HH, plus the amount of cow dung fed into a plant, have on the amount of gas produced by a plant?"

The other 3 variables (digester size, age and feeding frequency) were excluded from the list of variables meaning that these variables do not explain a further significant proportion of gas production. These assisted in answering the questions "What are the effects of digester size, ages and feeding frequency on the amount of gas produced by a plant?"

Table 16: Summary of the Stepwise Multiple Regression of Predictors of Gas Production

Variable	Multiple R	R square	R square change	B	Standardized Error-b	Beta	t	Significance of t
Cattle	.87	.75	.75	5.67	1.01	0.43	5.63	0.001
Dung fed	.92	.85	.10	0.027	0.00	0.42	6.32	0.001
HH size	.94	.088	.04	7.03	1.88	0.25	3.96	0.001

Only significant predictors are included

4.3.3 Analysis of Variance (ANOVA)

Analysis of Variance for correlated scores or repeated measures was carried out for the gas production in the various months of the study period (January to August). The correlated/related measures of variance indicate whether several (two or more) sets of scores have very different means (Howitt and Cramer, 2003). In such a case, it is assumed that a single sample of individuals has contributed scores to each of the different sets of scores and the correlation coefficients between sets of scores are large.

In the current study, the ANOVA was carried out on the gas production between the 8 months under study and the assumption was that the ambient temperature was the only independent variable contributing to gas production. Correlation between any two months varied between 0.74 and 0.97. This shows that there was no significant difference in gas production by the plants from one month to the next one.

The ANOVA results showed no significant difference in gas production between the 8 months under study ($F_{7.51}$=2.73, p=0.009). This data, therefore, assisted in answering the question; "What is the effect of ambient temperature on gas production by the fixed dome biogas plants). Table 17 displays ANOVA results summary.

Table 17: Analysis of Variance (ANOVA) Summary Table

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*-ratio
Gas productions	4795.17	7	685.02	2.73
Residual error	89703.45	51	251.27	

Significant at 5% level

CHAPTER FIVE

DISCUSSION

This section discusses the implications and significance of the research findings in relation to the 7 independent variables on gas production (dependent variable). These variables are the biogas plant size and age, number of HH members in the family that own a plant, number of cattle owned by the HH, amount of dung fed into the plant, rate at which the HH feeds the plant/digester (e.g. once a week or once a month) and the effect of the climatic variations over the ambient temperatures on gas production during the study period. The section ends up by discussing the implication of the amount of gas produced by the various sizes of fixed dome biogas units in relation to the broad objective of the study.

5.1 Effect of plant size

Plant sizes were between 8m^3(S8) and 35m^3 (S35) with the majority (37 out of 52) being 16m^3(S16). There was a positive correlation between digester size and biogas production ($r=0.57$, $p=0.000$ $p<0.001$). However, when this variable was considered together with the other variables, it was not found to contribute significantly in predicting the amount of gas that a plant produces (Table 16). As Figure 1 displays, the smallest plant size (S8) produced more gas than S10, S12 and S16. This is against a background where the average number of cattle for the HHs with the 4 plant sizes are four (Table 8) and the average amount of dung fed into the same plant size is 1,000 kgs.

This significant finding can be explained by the hydraulic retention time factor (HRT). The HRT gives the average time the material remains in the digester, which is equal to the amount of time the material is given to biodegrade (Koberle, 2007). If the same amount of waste is fed into different sizes of digesters, the waste in the smallest digester size will overflow faster, thus a shorter hydraulic retention time.

It has been shown that more than 75% of the total gas available in organic matter is recovered in 20 to 25 days. This is less than half of the recommended retention time of 50 days (Singh et al., 1985). Thus reducing the hydraulic retention time will reduce the size of plant and thus the construction cost. HRT, therefore, is one of the most important design parameters influencing the economics of digestion (Singh et al., 1985; Singh and Gupta, 1990; Parawira, 2004).

The formula for calculating the HRT is given by Koberle (2007) as;

$$HRT = \frac{\text{Effective digester volume in litres}}{\text{Daily Substrate Feed (DSF) in litres / day}} = [d]$$

In the present study, the estimated amount of cow dung added each day is 33 kg in both sizes of digester (Table 10). This is translated into a feed rate by multiplying by 2, as feedstock is diluted 1:1 (W/V) with water. Therefore, the retention time for the S8 and S 16 plants can be given as;

$HRT = \underline{8,000} = 121$ *days and* $HRT = \underline{16,000} = 242$ days respectively.

The HRT is over 2 times the recommended HRT in S8 and over 4 times in S16. This implies that waste which is producing little gas is retained for a long time in the digester. If the efficient HRT of 25 days is used, or even better that of 30 days to give an allowance for climatic variability, then the amount of cow dung fed into a plant would be calculated as follows;

$$30 = \frac{8,000}{2 \times \text{Cow dung (kg)}} = 133 \text{ kg per day} \quad \textit{and} \quad 30 = \frac{16,000}{2 \times \text{Cow dung (kg)}} = 267 \text{ kg per day}$$

thus 3,990 and 8,010 kg respectively for a calendar month of 30 days. As seen from Table 10, the maximum amount of waste fed into S8 during the study period was in the month of May when 1,260 kg was fed in. For S16, maximum feeding occurred in August, when 5,340 kg was fed into the plant that incidentally received more dung than any other plant size.

It can be concluded that plants were too large for the amount of available dung. This means that the farmers invested more in construction of the plants than they should have and the cost could have given the impression to other potentially interested farmers, that biogas was not economically viable. There is a need therefore, to focus on efficient HRT when calculating the size of a plant to be constructed.

Another design consideration influencing the economics of biogas plant construction is the cow dung to water dilution rate. The 1:1 weight/volume (W: V) is currently used in the study area. This ratio is stated in the manual of the Kenya National Domestic Biogas Programme (KENDBIP, 2009), the current major promoter of the technology in the country. However, it has been shown that the dilution rate can be reduced to 3:1 (W: V) of cow dung to water, using a HRT of 30 days, without affecting digester efficiency or gas productivity (Singh et al., 1984). This finding implies that, if instead of feeding 133 and 267 kg of waste into the S8 and S16 plants, 200 and 400 kg respectively of cow dung can be fed in, by adjusting the following formula to;

$$30 = \frac{8{,}000}{4/3 \times \text{Cow dung (kg)}} = \quad \text{and} \quad 30 = \frac{16{,}000}{4/3 \times \text{Cow dung (kg)}} = \quad 200 \text{ and } 400 \text{ kg per day}$$

This means that if farmers of the S8 and S16 digesters had only 133 and 267 kg of waste on a daily basis, then a more realistic calculation of efficient plant size becomes;

$$\frac{133}{200} \times 8 = 5.3 \quad \text{and} \quad \frac{267}{400} \times 16 = 10.6 \approx 11$$

Since plant designs for 5m^3 and 11m^3 size digesters are not in the market or in KENDBIP's, 2009 construction manual, the next best fit sizes would be 6m^3 (S6) and 12m^3(S12).

Therefore, if the HRT and dilution rates are taken into consideration, then the sizes of biogas plants can be greatly reduced, without affecting the amount of gas produced but with significant reduction in the construction cost. Construction cost has been found to be one of the main factors limiting in the uptake of the technology in the country (Mwirigi, 2011).

To illustrate this, two factors (number of cattle and available cow dung) were used in estimating the digester size for a farmer who has 1,000kgs of waste per month, (equivalent to 33kgs per day), The optimum plant size for this available feedstock is now; 33 X 4/3 X 30=1,320lts= 1.3 m^3. Since this digester size is not currently in the market, the next best fit would be 4 m^3, which is more than double the recommended size. In the study area, the majority of the farmers (52-56%) had between 2 and 3 cattle. By taking 3 which was also the mode, and using the same formula, it implies that majority of the plants should have been

$2m^3$, yet in reality, most of the plants (37 out of 52=71%), were $16m^3$. The $2m^3$ plant size corresponds to the size that was constructed for the Bagepalli biogas CDM project in India, whereby 5,500 plants of this size were constructed for farmers who have about 4 cattle per HH as described in CDM (2005).

Using the above findings, it is recommended that the formula for calculating the digester size use the 3:1 (W: V) cow dung: water dilution ratio and a hydraulic retention time (HRT) of 30 days, in order to minimize the size and thus the cost of plants, without affecting their efficiency and gas production. By using the current recommendation and 15kg cow dung per adult animal (the figure given by [KENDBIP, 2009]), the formula for calculating the digester size can now be;

Y=Z X 15 X 4/3 X 30=600Z this against the current formula in the area (Y=Z X 15 X 2 X 60=1,800Z)

Where Y= plant size (m^3)

Z= Number of cattle

15= amount of dung (kgs)/ cow/day

4/3 or 2 is the 3:1 and 1:1 dilution rates for the first and second formulas respectively while 30 and 60 are the HRT for the first and second formulas in that order. The number of litres is then divided by 1,000 to get the cubic meters (m^3).Thus the formula becomes:

Y=0.6Z

5.2 Effect of plant age

The ages of the plants under study was between 1 and 15 years and there was no significant correlation between the digester age and gas production ($r=-0.26$, $p=0.30$ $p<0.05$). This small reduction in gas production is observed but it is not significant. Hashimoto et al. (1981) suggested that reduction in gas produced in older plants occurs due to accumulation in the digester of inorganic material such as dirt and sand.

5.3 Effect of household (HH) size

The number of family members in a HH varied between 1 and 14 and the mode as well as the mean was 4 (Table 6). There was a strong correlation between the HH size and gas production ($r=0.71$, $p=0.000$ $p<0.001$). HH as a predictor of gas production was also ranked third after the number of cattle owned by an HH and the amount of dung fed into a plant. This implies that the larger the family size, the more gas their plant produces. This could be attributed to two factors which are labour availability and gas utilization. Murithi (2003) determined that an increase in the size of an HH leads to more people who are willing to contribute labour to farming activities. In the present study, this means that when the HH size increases, more waste is fed into the digester due to labour availability. Increase in waste fed to a digester has already been identified as the second most important predictor of gas production.

More family members require more food and thus a corresponding number of cooking hours and an increase in gas utilization. This justifies the effect of HH size on gas production. To have optimal gas production and utilization from a smaller sized family, voluntary labour can be substituted with paid labour, while increased gas demand can be from more end uses. In the current study, only 2 of the 52 farmers were using biogas for more than one use, the second use being lighting. This is against a backdrop where biogas has multiple uses; such as space heating, refrigeration, energy for mobile and stationary engines. Furthermore, there are usually many power black outs in the area, so biogas lamps or electricity produced through biogas generators, could be a more reliable substitute for grid electric lighting e.t.c.

5.4 Effect of the number of cattle owned by the HH

The number of cattle per HH fluctuated between 0 and 27. The majority of the farmers (56%) had between 2 and 3 animals (Table 8). Overall, the total number of cattle fluctuated between 187 and 193 during the study period. There was a strong correlation between the number of cattle owned by a HH and gas production by their digester ($r=0.87$, $p=0.000$ $p<0.001$). The number of cattle owned by a HH contributed the largest share to prediction of gas production, with a 75% share out of the 89% (Table 16). This means that the number of cattle should be the dominant consideration when calculating gas production by a plant and the size of the plant to be constructed. This finding is similar to that of a study carried out by the Kenya Integrated Household Budget Survey KIHBS (2005/2006), that found that of the 59.4% of the HHs that own cattle in the country, 41.2% own between 2 and 10 animals.

5.5 Effect of the amount of dung fed into the plant

An average of 1,000kg of dung was fed into all except the S35 plants sizes monthly (Table 9). However, individual plant breakdown shows that some plants were not fed at all in some months while others were fed as much as 5,000kg of dung in the same month. Explanations as to why some plants were not fed are given in the answers to the interview questions in Appendix 4 and are summarized below:

Answers included; i) Lack of water (cow dung was being mixed at a ratio of 1:1 W/V before feeding into the digester) ii) Loss of cows. The results of the inferential analysis showed a strong correlation (r=0.82, p=0.000 p<0.001) between the amount of waste fed into a digester and its gas production. Furthermore, the amount of dung fed into a digester contributed to the second largest share (10%) of gas production prediction (Table 16). From the discussion in section 5.1, it is clear that the plants were grossly underfed and this can be rectified by introducing more animals per farmer as dictated by the plant size. There are two limitations to this suggestion. The first is that the size of the farms are small, so to add more animals entails more feed for the animals and more land for the disposal of the slurry. Secondly, more gas would be produced and judging by current uses, farmers already get adequate gas for their needs (Mwirigi, 2011). The implication of producing more gas is that the farmers have to increase the usage or else the extra gas will be released to the environment unused. The latter will contribute to climate change instead of alleviating it. Adding more cattle in order to achieve additionality is therefore not viable.

5.6 Effect of the digester Feeding Frequency (FF)

The majority of farmers fed their plants either 1-5 days or more than 25 days in a month, which is equivalent to once a week or once daily. The correlation between FF and gas production was non significant (r=0.33, p=0.009 p< 0.001). In addition, inferential analysis excluded FF from the list of biogas production predictors. This means that although FF has some relationship with gas production, the association is not significant. This finding agrees with that of Hashimoto et al., (1981) who describe the losses to be through weathering, partial decomposition, and contamination of the feedstock with dirt and sand. Cornejo and Wilkie (2010) quote 70% as the amount of recoverable manure after handling and weathering. This study area is no different. For example, by taking an average dung production by one cow to be 15kgs, a quick calculation of the expected quantity fed into 8m^3(S8) and 16m^3(S16) in

January, when the total number of animals were 5 and 116 respectively (Table 8), the expected amount of dung should have been 2,325kg for S8 and 53,940 kg for S16. In reality, 1,614kg was fed in to S8 and 32,903 kg fed in to S16 (Table 10). This translates to 69% and 61% of the available feedstock. The higher % for S8 could be explained by the daily feeding regime, compared to others who feed their plants once a week.. It is therefore advisable to adopt the once daily routine of feeding the biogas plants.

5.7 Effect of the ambient temperature

The average monthly mean ambient temperatures varied between 18.2 ^{O}C and 20.5 ^{O}C, while the daily range was between 7 ^{O}C and 31.4 ^{O}C (Table 13). Variations in ambient temperature over the study did not significantly affect gas production ($F_{7.51}$=2.73, p=0.009). This could be explained by the fact that all the fixed dome digesters were underground and to ensure that they are stable and cannot explode under gas pressure, they are covered with a compacted layer of soil. Digesters have two compartments. The lower chamber contains the slurry and the upper contains the gas. For biogas plants that do not receive external heating, the slurry temperature reaches equilibrium, depending on; the design and capacity of the plant, the materials used for construction, environmental temperature and soil temperature (Singh et al., 1998). The same source reports that the temperature of the soil at the surface has a diurnal variation, while the temperature of soil at 2 m depth has no diurnal variation. Singh et al (1998) had similar results and found that there is a negligible diurnal variation in slurry temperature in fixed dome biogas units due to their large heat capacity. In this study, failure of the ambient temperature to affect gas production implies that the slurry compartments are more than 2 m below the ground level and thus the soil temperatures did not have an effect on slurry temperatures. Furthermore, the mean monthly temperatures are above 15^{0}C. Unheated and un-insulated plants do not work satisfactorily below 15^{0}C (gtz, n.d.)

This study was carried out using large biogas plants. Slurry compartments that are less than 2 m below ground may occur in plants smaller than S8 and thus their gas production might be affected by soil and ambient temperatures. The effect of ambient temperatures on plants smaller than 8 m^3 is therefore, an area for further research.

5.8 Gas production by the different sizes of fixed dome biogas plants

The largest plant size (S35) produced the highest amount of gas. This was unexpectedly followed by the S8. Using the gas production of 40 Lts of gas per kg of cow dung as given by (KENDBIP, 2009), a comparison of the expected and actual mean gas production by the S8 and S16 for the month of January gives 32.3/64.5 and 35.6/53.6 m^3 of gas respectively. This implies that there was maximum efficiency by the plants as they produced about twice of the expected gas. This can be explained by the long hydraulic retention times discussed in section 5.1, meaning that given the available cow dung, the plants cannot produce more gas.

The current study had sought to raise gas production from the current to a higher level so as to come up with the balance which is the additionality that is a prerequisite for CDM. Achieving this with this study group may be practical but has a lot of limitations as discussed in section 5.5. The study has however identified a significant finding concerning the size of digesters is concerned. The study, therefore, introduces a new concept of additionality that involves reduction in plant sizes by use of correct HRT and dilution rate with subsequent reduction in construction cost. This is projected to lead to an increased adoption of the technology by resource poor farmers who own two or three cows. The result of such adoption is both effective climate change mitigation and sustainable development.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The broad objective of this study was to establish the difference between current gas production and the predicted production provided by the study results. This would be the "additionality" aspect of the fixed dome biogas plants owned by farmers in Bahati, Kenya. Additionality is one of the key issues of the CDM for carbon trading. It was assumed that additionality would be achieved through analysis of seven factors; the sizes and ages of the biogas plants in the study area, the sizes of HHs that own the biogas plants, the number of cattle owned by each HH, the amount of dung that the HHs fed into their digesters, the frequency at which the digesters were replenished and finally the ambient temperature.

The results of the analysis showed, in order of significance, the number of cattle, quantity of feedstock (dung) and the size of the HH were the predictors of gas production. These three factors explained 89 % of the variance on the dependent variable, with the number of cattle contributing 75%.

The sizes of the biogas plants were too large for the available dung and neither the age of the plant nor climatic variations significantly affected the amount of gas it produced. Most of the farmers owned between 2 and 3 cattle and as expected, 70% of the available dung was fed into the digesters. The majority of farmers fed their plants either daily or once a week but the rate of replenishment had no effect on the amount of gas produced by a plant.

From the results and much discussion, it was concluded that the farmers under study cannot realize the aspect of additionality as stated in the literature review of this study (section 2.4). It was, therefore, concluded that additionality in biogas carbon trade can be realized through a different concept of "additionality". This is the type of additionality that utilizes the efficient method of estimating the size of a biogas plant so as to produce gas optimally in relation to the number of animals available and which due to the size of the HH or other means of gas utilization can all be used as it is produced. In so doing, the size of the plant will be affordable to many farmers. This will encourage adoption of the technology and the widespread uptake will be effective in climate change mitigation and sustainable development. It is proposed therefore, that massive adoption and not an increase by single HHs will be the additionality in a given CDM project boundary. The implication of this finding is that the rules of additionality must be changed from that of an individual's emissions reduction to that of a Programme of Activities (POA) in a project boundary. Further, this simple method of estimating the amount of gas that a biogas unit owner is likely to produce should be used to estimate the number of Certified Emission Reductions (CERs) that a biogas unit owner is entitled to. This would save them from the UNFCCC methodologies that are too complicated and which should perhaps only be used in developing countries that are at a much higher level of maturity.

6.2 Conclusions

6.2.1 Digester (plant) sizes

It was also noted that the plant sizes in the study area were too large for the available raw material. The sizes of future plants can be reduced such that they are big enough to just accommodate the available waste.

6.2.2 Ages of the biogas plants

The correlation between the plant age and gas production was not significant. This indicates that the active plant volumes did not decrease with age due to accumulation of indigestible inorganic materials as expected. This is possibly due to the fact that the zero-grazing units in the study area were made of concrete and thus contamination of the dung with inorganic materials such as soil and stones were minimal. It is advised, therefore, that farmers who intend to participate in carbon trade ensure that they keep their animals in similar conditions.

6.2.3 Household (HH) sizes

There was a statistically significant relationship between the HH size and gas production. Further the HH size was found to be one of the three important predictors of gas production. The importance of HH size in gas production is twofold. Firstly, it means that there is labour to feed the digester and secondly, it means that there is a higher demand for gas. It is therefore important that the digesters are fed regularly and the gas too must be used for effective climate change mitigation and sustainable development. Farmers with smaller

HHs could optimize gas usage through increased use of gas in devices other than cook-stoves. Another option is to extend connections to neighbors and sell the gas to them.

6.2.4 Number of cattle

Gas production is strongly correlated to number of cattle. In addition, the number of cattle owned by a HH contributed 75% to prediction of gas production. The number of cattle owned by a HH can therefore be used to estimate with 75% degree of precision the amount of gas that the HH can produce. The number of cattle owned by a HH has two major contributions. One is the relationship between the number of cattle and the size of a plant that should be installed. The second is the relationship between the number of cattle owned by a HH and the amount of gas produced. This can be extrapolated to estimate the number of Certified Emission Reductions (CERs) that the HH is entitled to and since the number of cattle owned by the study participants is close to the average for the country, the study recommendations are applicable to other digesters in Kenya.

6.2.5 Amount of dung fed into a digester

There was a strong relationship between dung fed into a plant and the amount of gas produced. In addition, the amount of dung fed into a plant was found to be the second largest contributor (10%) of gas production prediction. This could be explained by the plant being too big for the available dung and therefore all the dung was being fed into the plant. The amount of dung fed to a plant is important and the plant size constructed should be able to accommodate all the dung that is produced. The amount of dung can be estimated from the number of cattle owned.

6.2.6 Digester feeding frequencies (FFs)

Most of the farmers either fed their plants once a week or daily. The correlation between the digester feeding frequency and gas production had a was not statistically significant. Therefore, FFs were excluded from the list of the gas prediction variables. This suggests that, within the range trialed, it is the amount and not the rate of feeding that affects how much gas is produced in a month. This finding is on contrast to the findings of other studies which have found that only 70% of available dung is recovered for digester fed less frequently, due to weathering and handling.

6.2.7 Ambient temperatures

The results of the analysis of variance (ANOVA) statistical test showed no significant difference in gas production over the 8 months of study. This is an indication that gas production is not affected by the climatic variations through the year and can be explained by the fact that, in order to give the biogas plant structural stability, especially against the gas pressure inside, the top of the plant is usually at least 2munder the surface, covered by a compacted layer of sand. Previous studies have shown that the soil over 2m below the ground is not affected by the ambient temperature. In addition, the sizes of the digesters under study were over $8m^3$ giving them large heat capacities. It can be concluded that the gas production is not affected by the ambient temperature in these studies. However, in section 5.2.1 it was concluded that the size of the plant should be reduced in future; the effect of ambient temperature on smaller sized plants should be studied.

6.2.8 Gas production by the different sizes of fixed dome biogas plants

By comparing anticipated gas production with the measured (section 5.8), it was discovered that the plants are producing to their maximum and thus gas production optimization which had been the aim of this study, is not feasible. Therefore, additionality, as the study intended to bring it out is not possible. However, it has been shown that it is possible to significantly reduce the sizes of the plants without affecting gas production. Smaller sizes mean affordability and thus widespread adoption. This implies that more plants will be constructed with resulting effective climate change mitigation. In addition to that, smaller plant mean that fewer construction materials will be used by each plant owner thus the balance is used by another owner. This is what is referred to as sustainable development where the present generation utilizes environmental facilities economically so that they are availed to the next generation. Further, smaller plant sizes take a short time to put up and the masons; therefore have more time to construct the much needed number of plants that are effective in climate change mitigation

6.3 Recommendations

6.3.1 Recommendations based on research findings

6.3.1.1 Plant sizes

- Plant sizes for farmers who own up to ten animals should not exceed 8 m^3
- Since the very small sizes of say 2m^3 might not have adequate internal gas storage, HHs can either use the gas on a continuous basis or install external storage to ensure a steady supply of gas when they are cooking

6.3.1.2 Plant ages

Animals should be kept in zero grazing units with floors that will not contaminate dung with soil, stones and other dirt.

6.3.1. 3 Household (HH) sizes

A HH that is not able to use all the gas for cooking should increase other uses for instance for lighting and electricity generation. Alternatively it can sell the gas.

6.3.1. 4 Number of cattle

- The number of cattle owned by a HH should be used to estimate the size of the plant constructed. The HH should use the formula: Z=0.6Y where Z is the size of the digester, 0.6 m^3 cow^{-1} is a constant and Y is the number of cattle it owns
- The number of cattle owned by a HH should be used with 75% precision to predict the amount of gas that it is likely to produce and by extrapolation how many carbon credit units should be claimed. Credits calculated this way should be taken as the additionality for farmer to earn an income without the difficulty of using the current UNFCCC methodologies which should be used only for developing countries that are at a higher level of development. This income can provide a subsidy that will make the plants affordable to the resource poor farmers.

6.3.1.5 Dung

All available dung should be fed into the plants

6.3.1.6 Feeding Frequency (FF)

Daily feeding of the plants is highly encouraged

6.3.1.7 Ambient temperature

Ensure the plants are 2m or more below the ground surface so as to minimize the effect of ambient temperature on gas production.

6.3.2 Further research

The current study has made the following observations which would necessitate further research:

6.3.2.1 Effect of ambient temperature on gas production

This study suggested that ambient temperature had no effect on gas production. However, this was in plants that were over $8m^3$ and which due to their large sizes, were deep in the ground. A reduced size, as recommended here, might be nearer to the surface and also due to its small size, has a lower internal heat capacity will not be as high. It is recommended that further studies be carried out to investigate the effect of ambient temperature on plants less than $8m^3$.

6.3.2.2 Estimating plant sizes for materials from other livestock species

This study has concentrated on cow dung, but Kenya has biogas production potential from other livestock, such as poultry and pigs. Estimating plant sizes using other livestock waste is therefore another important area for further research.

6.3.2.3 Estimating plant sizes by farmers with various feeding regimes

This study was carried out on animals that were fed mainly with napier, grass, some hay during the dry seasons and supplemented with concentrates, such as dairy meal, during the milking time. However, Hashimoto *et al.*, (1981) had shown that feeds with less roughage produce more gas due to their lower lignin levels. The actual size of a plant for farmers who feed their animals with more concentrates is the subject of ongoing research.

These are mostly farmers in large scale production of more than the 10 animals that are found in the study area.

6.3.2.4 Predicting gas production by fixed dome biogas units

The current study demonstrated that the number of cattle owned by a HH, the amount of dung fed into a digester and the HH size explain 89% of the gas production variance. Further research is required to find out which other factors explain the remaining 11%.

LIMITATION OF THE STUDY

Most of the pipes and fittings that were used to install the biogas flow meters were made of polypropylene random copolymer material commonly known as (PPR). Polypropylene (PP) is a thermoplastic polymer used in a wide variety of applications (Wikipedia, n.d.). Joining of these fittings and materials required an electric pipe welding machine which had to be hired but could not be used in areas with no electricity. Lack or inadequacy of this device led to the innovation of a welding tool for PPR pipes and other fittings that could use charcoal, biogas or wood fire instead of electricity. Figure 15 displays the standard electric and the invented new design of devise.

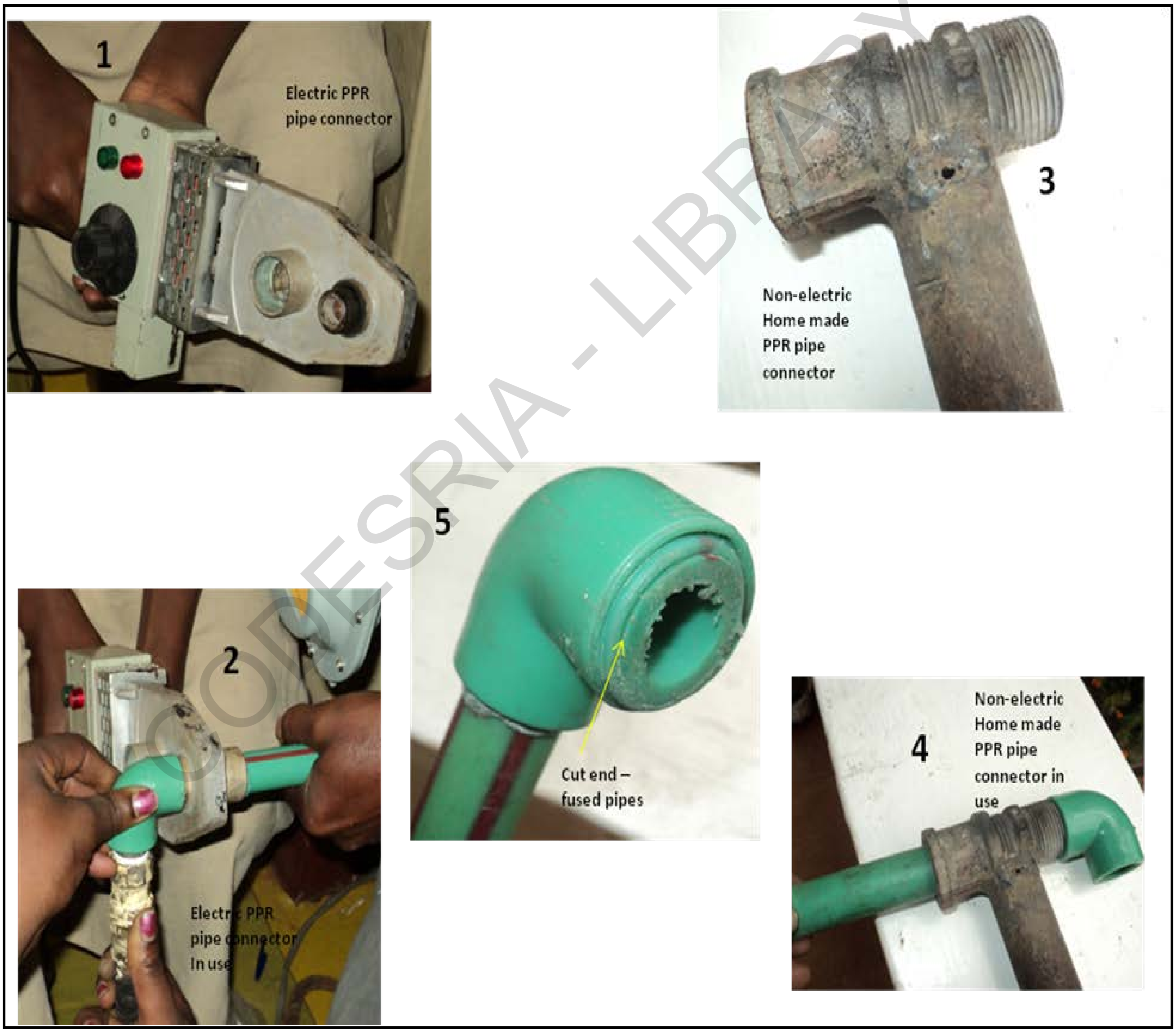


Figure 15: The standard electric (1, 2) and invented (3, 4) PPR pipe welding devices plus a cut edge of fused pipe and elbow fitting (5)

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APPENDICES

Appendix 1: Annex 1 Countries and the Initial Assigned Amounts of Carbon Dioxide

Annex 1 Party	Tonnes of Carbon Dioxide Equivalent	Annex 1 Party	Tonnes of Carbon Dioxide Equivalent
Australia[a]		Latvia	119,182,130
Austria	343,866,009	Liechtenstein	1,055,623
Belarus		Lithuania	227,306,177
Belgium	673,995,528	Luxembourg	47,402,996
Bulgaria	610,045,827	Monaco	495,221
Canada	2,791,792,771	Netherlands	1,001,262,141
Croatia[a]		New Zealand	309,564,733
Czech Republic	893,541,801	Norway	250,576,797
Denmark	276,838,955	Poland	2,648,181,038
Estonia	196,062,637	Portugal	381,937,527
European Community	19,621,381,509	Romania	1,279,835,099
Finland	355,017,545	Russian Federation	16,617,095,319
France	2,819,626,640	Slovakia	331,433,516
Germany	4,868,096,694	Slovenia	93,628,593
Greece	668,669,806	Spain	1,666,195,929
Hungary	542,366,600	Sweden	375,188,561
Iceland	18,523,847	Switzerland	242,838,402
Ireland	314,184,272	Ukraine	4,604,184,663
Italy	2,416,277,898	UK of Great Britain & Northern Ireland	3,412,080,630
Japan	5,928,257,666		

- Source: UNFCCC(2008)
- [a]At the time of publication of this data, the reviews of the initial reports of Australia and Croatia were still in progress
- Above figures are the initial assigned amount of parties included in Annex 1 to the Convention that are also parties to the Kyoto Protocol

Appendix 2: Waypoints and Altitudes of the Plants under Study

METER NO	SOUTH	EAST	HEIGHT (MASL)
1	00.23574	036.11065	2017
2	00.23501	036.10700	2040
3	00.23272	036.10707	1950
4	00.22906	036.11382	1953
5	00.22895	036.11381	1998
6	00.22893	036.12564	1956
7	00.23706	036.11454	1881
8	00.24743	036.13502	1919
9	00.24807	036.13391	1915
10	00.23824	036.15477	1970
11	00.22205	036.12378	1961
12	00.23216	036.13996	1947
13	00.21724	036.12798	1970
14	00.24336	036.12601	1907
15	00.24445	036.12767	1915
16	00.24335	036.13081	1918
17	00.24796	036.13127	1916
18	00.24962	036.14836	1948
19	00.25768	036.13102	1900
20	00.27096	036.13320	1892
21	00.26938	036.13980	1904
22	00.28137	036.13020	1884
23	00.28806	036.13726	1891
24	00.28850	036.13650	1892
25	00.29293	036.15063	1894
26	00.17693	036.18505	2262
27	00.28582	036.13722	1893
29	00.27092	036.13011	1887
30	00.27225	036.12982	1885
31	00.24635	036.16520	1970
32	00.24597	036.14375	1943
33	00.28003	036.12573	1878
34	00.26256	036.11782	1889
35	00.26103	036.12269	1889
36	00.25831	036.12309	1901
37	00.26584	036.10486	1919
38	00.21769	036.12939	1975
39	00.18845	036.12287	1952
40	00.18822	036.12282	1951
41	00.16132	036.14262	2041
42	00.15357	036.15058	2085
43	00.15959	036.13779	2047
44	00.17098	036.12832	1988
45	00.21658	036.12579	1968
46	00.21543	036.13038	1972
47	00.18843	036.12219	1954
48	00.18832	036.12359	1952
49	00.27723	036.13504	1887
50	00.28106	036.13168	1890
51	00.28132	036.13569	1891
52	00.25753	036.13550	1911
53	00.27160	036.13852	1904

Note: Meter number 28 failed and thus not appearing in the list.

Appendix 3: The Digester Feeding Form for the Month of April for Meter No. 53

Zero-Grazing

53

Appendix 3: Replenishment and Amount's Recording Form

Month/Year- **April 2011**

Number of Plant Owner --53--Year Plant was constructed-2007--Age (yrs) of the plant-4 yrs

Size of the Digester 16 m^3

Name of Plant owner-

Sub-location-Kianuingeri

Number of Cattle--5

1 wheelbarrow = 40kg

Plant Coordinates X---------Y------------ (*Please don't fill this row*)

Day NO.	DATE	Temp °C	Replenished √	Amount (Kgs)	Remarks- Like it was raining etc
1	Friday		✓	1 wb	
2	Saturday		✓	1 wb	
3			✓	1 wb	
4	Monday		✓	1½ wb	
5	Tuesday		✓	1½ wb	
6	Wednesday		✓	1 wb	
7	Thursday		✓	1 wb	
8	Friday		✓	1 wb	
9	Saturday		✓	1 wb	
10			✓	1 wb	
11	Monday		✓	1 wb	
12	Tuesday		✓	1 wb	
13	Wednesday		✓	1 wb	
14	Thursday		✓	1 wb	
15	Friday		✓	1 wb	
16	Saturday		✓	1 wb	
17			✓	1 wb	
18	Monday		✓	1 wb	
19	Tuesday		✓	1 wb	we cooked githeri
20	Wednesday		✓	1 wb	
21	Thursday		✓	1 wb	
22	Friday		✓	1 wb	
23	Saturday		✓	1 wb	
24			✓	1 wb	Had visitors
25	Monday		✓	1 wb	
26	Tuesday		✓	1 wb	
27	Wednesday		✓	1 wb	
28	Thursday		✓	1 wb	
29	Friday		✓	1 wb	
30	Saturday		✓	1 wb	31 wheelbarrows

1. The form except the column on temperature will be filled by the **cattle attendant** and will be located at the zero grazing unit
2. Mark with a tick (√) against the day you replenish the digester
3. Temp °C is the mean daily temperature obtained from the Meteorological station adjacent to the study's administrative location
4. Column on temperature (grey color) to be filled by the researcher (Please don't fill anything in it)
5. **This Form for this month will be collected between 1st and 5th of next month**

Kgs = 1,240

Days = 30

Appendix 4: Answers to probing questions

No.	Question	Answers
1	In your opinion, what lead to more gas being produced in the current month compared to previous month?	1. Added urine 2. Removed water blockage from gas pipe (2) 3. Spouse returned from a long journey 4. Added poultry waste
2	In your opinion, what lead to less gas being produced for the current month compared to previous month?	1. Loss of a cow (3) 2. No water
3	In your opinion why does your plant produce more gas than others of the same size, make and feeding amount and frequency?	Supervise feeding of the plant and also use gas to heat kitchen, dairy and bathing water. Ensure the cooker is on most of the time
4	In your opinion why does your plant produce less gas than other plants of the same size, make and feeding amount and frequency?	1. No water (3) 2. Don't know (4)
5	Why did your plant produce no gas?	1. Blockage 2. Don't know
6	Observations explaining the "don't know" answers	1. More gas than expected • Urine and washings from the dairy unit 2. Less gas than expected • Unrepaired leakages • Dairy unit not cemented thus suspected digester volume reduced by accumulated sand (3)

Note: Figures in brackets indicate the number of similar responses

Appendix 5: Gas Production-Filled Form for the Month of May for meter No. 46

Kitchen

(46)

Appendix 2: Geographical Location, Household Size, Number of Cattle and Gas Quantity Recording Form

Month/Year-**May 2011**

Meter Number 046 Year Plant was constructed 2001 Age (yrs) of the plant 10YRS

Name of Plant owner- ------- Size of Digester -16- m³

Sub-location---THAYU--------

Number of Cattle----5-----------

Plant Coordinates X---------Y------------ *(Please don't fill this row)*

Household Size (Average Number of Members Present during the month) ---3----------

Date	Day	Gas Meter Reading	Units Consumed(Don't Fill)	Remarks – Like had visitors, was absent
1	Sunday	0309.157		
2	Monday	0311.717		
3	Tuesday	0314.258		
4	Wednesday	0317.216		
5	Thursday	0320.104		
6	Friday	0322.105		
7	Saturday	0326.308		
8	Sunday	0329.067		
9	Monday	0332.120		
10	Tuesday	0334.819		
11	Wednesday	0338.327		
12	Thursday	0340.848		
13	Friday	0343.432		
14	Saturday	0346.546		
15	Sunday	0350.104		
16	Monday	0353.316		
17	Tuesday	0356.659		
18	Wednesday	0359.785		
19	Thursday	0362.258		
20	Friday	0365.321		
21	Saturday	0369.045		
22	Sunday	0372.179		
23	Monday	0374.857		
24	Tuesday	0377.740		
25	Wednesday	0380.921		
26	Thursday	0383.608		
27	Friday	0385.900		
28	Saturday	0389.229		
29	Sunday	0392.019		
30	Monday	0395.676		
31	Tuesday	0398.821		

- Form to be filled by household head and or gas user and to be located inside the house and next to the gas meter
- Consumed Units (grey color) to be calculated and filled by the researcher
- **This Form for this month will be collected between 1st and 5th of next month**

$m^3 = 89$

Appendix 6: Installed meter and a meter's reading display

1. New Meter

2. Installed Meter

3. Working Meter-
Reading 89.92 m^3

Appendix 7: Weather summary for the month of August

KENYA METEOROLOGICAL DEPARTMENT
COMPUTATION SHEET FOR THE MONTHLY WEATHER SUMMARY
MONTH :AUGUST 2011

DATE	TEMPERATURE ^{0}C				DEW POINT ^{0}C			RELATIVE HUMIDITY%		PRESSURE (CLP)		SUNSHINE	RADIATION	EVAPORATION	RAIN	DAYS WITH			WINDRUN
	MAX	MIN	MEAN	LGM	0600Z	0900Z	1200Z	0600Z	1200Z	0600Z	1200Z	HRS	MJM^{-2}	MM	MM	5RAIN	THUNDER	HAIL	Kms/day
1	24	13	18.5		12.5	12.1	14.3	75	55	812.8	809.9			5.0	0.0				106.93
2	23.9	12.4	18.2	-	11.3	11.8	12.7	72	48	813.8	812.5			4.0	0.0				106.99
3	25.5	12	18.8	-	11.1	12.1	12	77	46	813.9	811.7			5.0	0.0				116.4
4	23.5	12.8	18.2	-	9.9	11.5	10.4	69	43	814.8	814.8			5.0	0.0				129.61
5	23.8	14.4	19.1	-	12	9.6	9.1	79	41	815	813.4			5.0	0.0				137.94
6	24.8	13.2	19	-	10.7	10.7	10.4	70	41	815.2	811.7			4.8	1.8	*			119.2
7	23.9	14.2	19.05	-	12.3	12.0	11.2	74	50	813.2	812.5			2.0	0.0				126.32
8	24.0	14	19	-	11.9	11.2	10.8	76	46	814.5	811.8			3.5	TR				102.8
9	20.9	14	17.5	-	13.1	12.4	12.2	85	58	814	813.1			2.6	0.6				44.7
10	24	14.4	19.2	-	14.7	14.6	12.2	89	59	813.2	811			3.3	22.8	*	*		93.46
11	22	14	18	-	13.5	14.4	14.2	86	86	813.2	811.6			0.6	12.1	*	*		63.54
12	22	11.4	16.7	-	13.7	14.3	14.6	93	70	813	809.8			1.0	26.0	*	*		67.56
13	23.6	12.5	18.05	-	14.5	14.5	15	90	59	811.9	809.7			3.3	12.8	*			85.76
14	24.0	13	18.5	-	14.2	15.1	13.4	90	51	811.4	810.5			2.7	2.2	*			73.52
15	21.4	12.0	16.7	-	14.4	14.4	13.2	86	65	813.2	811.1			2.5	TR				71.61
16	24.1	12.5	18.3	-	13.7	14.5	11.7	84	64	813.4	812.1			/	TR		*		84.78
17	24.3	11.5	17.9	-	11.3	12	12.1	76	50	813.7	811			3.2	4.2	*	*		72.33
18	22.5	13.5	18	-	12.8	12.5	11.3	81	58	813.9	811.4			1.6	3.1	*	*		63.52
19	24.1	10.2	17.15		12.8	13.3	13.7	90	55	813.8	811.5			4.0	0.0				98.98
20	25.2	10.2	17.7		11.7	12.9	11.8	80	44	813.5	812.3			3.0	0.0				68.61
21	24.8	9.6	17.2		10.6	11.7	13.3	79	53	813.8	811.4			4.3	5.3	*	*		90.39
22	23.8	12.7	18.25		12.8	14.1	10.8	76	53	813.8	811.5			4.0	0.0				85.64
23	25.2	12.2	18.7		12.5	13.3	11.4	77	48	813.5	813.3			4.0	0.0			/	99.18
24	26.5	11.2	18.85		11.6	12.7	13	77	45	8137	810.5			4.3	13.3	*	*		78.27
25	23.5	13.3	18.4		13.9	14.3	13.4	81	55	813.7	810.7			2.7	5.2	*	*		98.31
26	23.6	13.8	18.7		14.8	14.4	12.5	95	72	813.6	811.9			2.3	0.3		*		76.04
27	24.6	12.6	18.6		14	14.5	15	83	55	814.1	813.5			4.0	4.0	*			76.33
28	23.6	12.4	18		13.2	15.2	12.4	78	54	813.9	813.9			4.2	1.2	*			131.69
29	21.4	14.1	17.75		12	13.4	13	76	58	814.1	812.1			2.0	TR				89.59
30	25.1	12.6	18.85		12.5	12.3	11.6	77	43	813.9	812.2			1.0	9.0	*	*		87.14
31	24.3	10.2	17.25		12.9	12.9	13.0	84	49	814.4	812.3			6	0				87.14
SUM	737.9	389.9	564.05	0	392.9	404.7	385.7	2505	1674	32547.2	25166.7	0	0	100.9	123.9	14	11	0	2834.28
MEAN	23.8	12.6	18.2		12.7	13.1	12.4	80.8	54.0	1049.9	811.8			3.4	4.6				91.4
HIGHEST	26.5	14.4	19.2	0.0	14.8	15.2	15.0	95.0	86.0	8137.0	814.8	0.0	0.0	6.0	26.0	0.0	0.0	0.0	137.9
LOWEST	20.9	9.6	16.7	0.0	9.9	9.6	9.1	69.0	41.0	811.4	809.7	0.0	0.0	0.6	0.0	0.0	0.0	0.0	44.7

Appendix 8: Publication/Innovation Registration in Progress

1. Mwirigi, J. W., Makenzi, P.M., and Ochola, W.O. (2013?). Climate Change Mitigation and CDM through Biogas Technology: Changing the "Additionality" Rules for Greater Participation by Kenyan Farmers: *Energy Policy*. Manuscript No: JEPO-D-12-00914
2. Innovation in the registration process "Non-electric PPR Pipe and Fitting's Welding Tool" Kenya Industrial Property Institute's (KIPI) Application No. KE/U/2012/000268 of 03/05/2012.