CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

1.1.1 Crop and animal wastes in Uganda

In Uganda, waste is a growing problem especially in urban and peri-urban areas. This is largely due to increasing consumer demand for foodstuffs that are marketed in raw form (Ekere et al., 2009). The marketing of raw unprocessed foods means that the task of processing them is carried out by the final consumers resulting into massive accumulation of waste in homesteads and urban areas. Estimates of crop and animal wastes are divergent. Kampala City alone generates about 40,000 tonnes of household and market wastes annually with a collection of only 36% (Kampala City Council, 2002). In contrast, Mwesigye and Sabano (2003) put daily solid waste production by Kampala's population of about 1.2 million, at about 900 metric tonnes with only a collection capacity of about 45%.

Composting and burning of waste are the most common ways of managing waste in the rural areas (Ekere et al., 2009) whereas sanitary landfills continue to be largely the common disposal method for urban waste. In Kampala city, for instance, land filling is the only formal way of waste disposal (Kampala City Council, 2002). However, such landfills inevitably generate waste management problems (Zamorano, 2005) and as noted by Kahn (1998), developing new landfill sites or technical situations to waste disposal (such as incineration) treat only the symptoms of the problem but not the problem. Waste disposal in landfills can generate environmental problems such as water pollution, unpleasant odours, explosion and combustion, asphyxiation, vegetation damage, and greenhouse gas emissions (Department of the

Environment UK, 1995; Popov, 2005). These problems render the whole waste collection operation unsustainable. Appropriate and sustainable solutions must therefore be devised to deal with the eminent problem of waste. One sustainable approach to manage the large quantities of animal and crop wastes and increase their value is to use them as an energy resource. Through appropriate conversion technologies, animal and crop wastes can be a good source of raw materials for the generation of renewable energy. This can lead to the attainment of the twin objective of sustainable waste management strategy and augmenting other energy sources to foster socio-economic development of the country.

1.1.2 Energy sector as an engine of socio-economic development

Energy is an important ingredient for the development process of any country. Energy consumption level is a good indicator of socio-economic development level of a country because the energy sector has strong impact on poverty reduction through income, health, education, gender and the environment linkages (Sayin et al., 2005). In modern times, no country has managed to substantially reduce poverty without greatly increasing the use of energy or efficiently utilizing energy and/or energy services (Rao et al., 2009). In fact, energy affects all aspects of development – social, economic and environmental (Amigun et al., 2008). Therefore, the strategy adopted by a country in energy use is a fundamental tool in achieving economic development since economic prosperity and quality of life of a country are closely linked to the level of its per capita energy consumption (Singh and Sooch, 2004). Therefore provision of adequate, affordable, efficient and reliable energy services with minimum effect on the environment is crucial. However, in Uganda, like in many other developing countries, while demand for energy is continuously increasing, its supply is not increasing proportionately (Chen et al., 2009). Efforts to increase energy supply in a bid to match the increasing energy demand have to be sought. Thus the use of animal and crop wastes to boost energy supply in Uganda becomes an important and readily available option.

1.1.3 An overview of the energy sector in Uganda

Uganda is endowed with different energy sources including hydro, geothermal, biomass, wind, solar and more recently, fossil (petroleum) fuels. These sources can be broadly classified into three groups: traditional (biomass), commercial (non-biomass) and alternative energy sources. Traditional energy includes fuelwood and agricultural residues for domestic use. Commercial energy comprises electricity and petroleum products, while alternative sources include renewable energy such as biogas and solar energy.

However, like in many developing countries, there is over-dependence on few conventional energy sources comprising biomass (firewood, charcoal, crop residues, etc), petroleum products and grid electricity as the driver of economic development. Biomass is the main source of energy for domestic use, contributing 93%, followed by petroleum with 6% and electricity with 1% (Sebitt et al., 2004). Firewood is the most common cooking fuel, particularly in rural areas, and is used by 82% of households, while 15.% use charcoal with only 3% using electricity (MFPED, 2002). Use of commercial fuels such as liquefied petroleum gas and kerosene (paraffin) for cooking in rural areas is insignificant but kerosene is the major source of lighting for more than 90% households in rural areas and 58% in urban areas (Ministry of Finance Planning and Economic Development (MFPED), 2002).

With the diverse endowment of energy sources, Uganda should not be experiencing the current acute energy supply deficit, particularly with per capita energy consumption among the lowest in the world (MEMD, 2002). The shortages are further aggravated by the annual population growth rate of 3.7% and annual growth in demand for electricity of 7-8% (Ministry of Energy and Mineral Development (MEMD), 2004). The current acute energy supply deficits are largely due to the over-dependence on the few traditional energy sources despite the rich endowment of energy resources that could be used to diversify the energy sector.

The dependence on few conventional energy sources in Uganda, especially fossil fuels for her energy needs is increasingly becoming unsustainable because fossil fuels cause ecological and environmental problems (Karekezi, 2002a) and are depleting rapidly. This poses a huge challenge to the energy sector, requiring that supplementary energy sources be sought. Problems associated with non-sustainable use of fossil fuels have led to world-wide increased awareness and widespread research into the accessibility of new and renewable energy resources (Amigun and von Blottnitz, 2007). This awareness and concern about the environmental impacts of fossil fuels coupled with steep increases in oil prices have lent enormous weight to the argument for countries switching to renewable energy sources (Akinbami et al., 2001). The development of renewable energy has been identified as the option for addressing power problems in the developing countries (Karekezi, 2002b).

While many countries have already embraced and are heavily investing in renewable energy sources, in Uganda, the interest in renewable energy sources is a relatively recent one (MEMD 2002). The combined contribution of the new and renewable sources of energy to the total energy consumed is estimated at only one percent (MEMD, 2002). However, efforts to evaluate renewable energy sources option to complement the traditional sources and mitigate the current energy crisis in Uganda have been stepped up. There is a growing interest in evaluating biogas energy for this purpose because of its advantages over other renewable energy sources.

1.1.4 The importance of Biogas as a renewable energy source

Animal and crop wastes are an important source of renewable energy through the process of anaerobic digestion. Anaerobic digestion, a biological conversion process, has a number of advantages for waste conservation and is an important renewable energy source. Fresh animal or crop wastes with high moisture content (about 80%) that makes them unsuitable for most thermo-chemical processes can be easily fermented using the anaerobic digestion method (Park et al., 1998) to produce biogas. Biogas consists of between 40 and 70% methane, with the remainder being carbon dioxide, hydrogen sulphide and other trace gases (Singh and Sooch, 2004; Shin et al., 2005; Batzias, 2004).

Biogas energy, a clean and renewable form of energy, could augment conventional energy sources because of its environment friendliness allowing for efficient waste utilization and nutrient recycling (Bhat et al., 2001). Generally, biogas digesters have come to symbolize access to modern energy services in rural areas and are slated to considerably improve health and sanitation, and to yield significant socioeconomic and environmental benefits (Srinivasan, 2008). It is a versatile source of energy which meets several end uses, including cooking, lighting and motive power generation (Rubab and Kandpal, 1995). When used as a cooking fuel, it provides for better combustion than the less efficient cooking fuels like fuelwood. It is comparatively clean and hygienic (Jingura and Matengaifa, 2008) because bacteria and other pathogens are destroyed through anaerobic treatment. By substantially reducing drudgery for women (Mwakaje, 2008) and indoor smoke and resultant ocular and respiratory infections, biogas digesters contribute to improved health and reduction in medical expenditure (Srinivasan, 2008).

Biogas technology has no geographical limitations (Taleghani and Kia, 2005) and is produced mainly from raw materials that are locally available making it a cheaper and simpler option (Gautam et al., 2009). In addition, these energy resources can be developed extraordinarily rapidly and enables the valuable by-products of the process – methane, fertilizer and solid fuel content – to be harnessed in controllable, containable and useable quantities. In short, it actually transforms a costly problem into a profitable solution (AFREPREN, 2004).

Furthermore, the development and utilisation of biogas energy will improve the quality of life, and provide a dependable power supply to the rural and urban areas (Iniyan and Jagadeesan, 1997). Bioenergy can contribute to the generation of new jobs especially in rural and farming communities, which, in turn, may result into the improvement of income distribution (Erdogdu, 2008). Akinbami et al. (2001) adds that generally the new and renewable energy resource systems also offer attractive prospects because they preserve ecosystems and retard degradation of the environment. Biogas energy has formidably positive environmental properties, resulting in no net releases of carbon dioxide and very low sulphur content (Erdogdu, 2008). Biogas technology leads to a reduction in greenhouse gas emissions (Han et al., 2008), eutrophication and air pollution, and improves utilisation of crop nutrients (Lantz et al., 2007). In fact, a proper functioning of biogas system in particular can provide multiple benefits to the users and the community resulting in resource conservation and environmental protection (Yadvika, 2004).

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

There are several reasons why biogas energy in particular seems an appropriate and important option to augment Uganda's conventional household energy shortages:

(i). Animal manure is widely available in most parts of the country because livestock production is an important economic activity in almost all regions of the country (Pandey et al., 2007). Biogas can be generated throughout the year because of the suitable temperature for anaerobic fermentation process in the tropics. Since Uganda lies across the equator, temperatures are fairly constant throughout the year, and always above 15°C.

(ii). Uganda is facing serious electricity shortages because of heavy dependence on few conventional unsustainable fossil and biomass energy sources (MEMD, 2002). The high prices for petroleum products and unsustainable pressure on the country's forest biomass are exacerbating the current energy crisis in Uganda. Production of biogas fuel at the household level using local, renewable resources reduces the pressures on forestry, centralized electricity production, and fossil fuel distribution networks (Pandey et al., 2007).

(iii). Animal manure is not methodically composted and integrated into farming practice in Uganda. At the same time Uganda is one of the lowest per hectare users of imported fertilizer in Africa with the largest farm area among countries in Africa certified for organic farming. Increasingly, intensive agriculture with limited return of nutrients is rapidly exhausting the soils. Biogas digesters perform the task of collectors of under-utilized dung, and with sufficient awareness through biogas energy production and utilization, fertilizer nutrients can be recycled to farms to preserve the fertility of the soil.

1.2 Problem Statement

The increasing interest in renewable energy sources in Uganda has been particularly compelled by the increasing magnitude of waste generation and concentrations of confined animal feeding operations in the peri-urban and urban areas. There is a growing concern over the potential impact on environmental quality and socio-economic consequences caused by the generated wastes (Kampala City Council, 2002; Ekere et al., 2009). The accumulation of the wastes and lack of safe waste handling practices creates environmental and health problems. Poor waste collection practices attract and promote the breeding of undesirable and potentially disease transmitting insects and other pathogens (Zamorano, 2005).

Land filling, the only form of waste disposal now employed, can no longer cope with the alarming rate of waste generation in Uganda. Yet amidst this waste management paradox, Uganda is experiencing an acute energy supply crisis (MEMD, 2002) that has greatly affected the socio-economic development of the country.

The existence of policies supportive of rural energy investments and institutional mechanisms that have been built through earlier work by the government and private sectors in Uganda, coupled with the energy crisis in the country, provide a conducive entry point for an integrated household-level biogas program in the country (Pandey et al., 2007). Further, there also exist favourable technical conditions for the production of biogas energy in Uganda. These include availability of abundant biodegradable animal and crop waste raw material, warm tropical temperatures and availability of field–tested technologies.

This implies there is a prima facie concurrence of favourable circumstances (Renard, 1988). Biogas technology is not also a recent introduction in Uganda, with some pilot and promotional biogas projects stretching as far back as the 1950s (Nabuma and Okure, 2004).

Despite all the numerous advantages and demonstrated experiences of biogas production and utilization as a renewable energy source and good waste management strategy, the potential of biogas energy has not been fully tapped in Uganda. The development and utilization of this desirable, modern, ecology-oriented and friendly form of appropriate technology remains low (Pandey et al., 2007) and its adoption remains dismal. Biogas energy production and utilization still do not have a foothold in Uganda and the socio-economic and environmental potential of the technology has largely remained elusive. The reasons for this trend remain by and large obscure. This has therefore generated a number of research questions that this study attempted to address. For, instance:

1) What is the current and potential level of biogas generation and utilization in Uganda?
2) How economically viable is biogas technology as an alternative source of energy?
3) Why has biogas technology failed in the country despite the prevailing favourable technical conditions?
4) What are the stakeholders' perceptions on the production and use of biogas energy in Uganda?

Limited studies have been carried out to provide answers to these key questions. It was against this background that the socio-economic evaluation of biogas technology was considered imperative to explore its potential, adoptability and functionality in Uganda.

1.3 Objectives of the study

The main objective of this study was to evaluate the socio-economic viability of biogas production and utilization in Uganda. The specific objectives were:

1. To analyse the key socio-economic factors influencing biogas energy production and utilization from family sized digesters in Uganda.
2. To assess the key household user perceptions of and preferences for biogas energy in Uganda.
3. To determine the economic viability of biogas technology as an alternative energy source for cooking and lighting in Uganda.
4. To estimate the potential biogas energy generated from animal waste in Uganda

1.4 Hypotheses

The following hypotheses guided this study:

1. Production and utilisation of biogas energy in Uganda is a profitable venture.
2. User perceptions of and preferences play a significant role in the choice of household energy sources, including biogas energy in Uganda.
3. Socio-economic factors significantly influence the production and utilization of biogas in Uganda.

1.5 Justification for the study

Biogas technology potentially represents one of the household and/or community-level technologies that offer the possibility of more decentralised approaches to sustainable development (Raven and Gregersen, 2005). However, large-scale investment in biogas energy technology requires first an assessment of its socio-economic viability as an alternative source of energy. As Hall et al. (1992) notes, a number of developing countries could adapt and improve the technologies for modern bio-fuels but the contentious problems are with economics. Ni & Nyns (1996) also note that the development and management of biogas technology are far from a pure technical question but rather relate to economic and social problems with human behaviour. Socio-economic appraisal of the technology is required to quantify the significant benefits and costs accruing to biogas energy production and utilization and identify critical factors affecting wider use of the technology.

Sometimes because of the lack of awareness regarding just the selection of a suitable model and size of biogas plant, the full potential of the biogas producing material is not harnessed, and the economic viability of the technology is rendered doubtful (Singh and Sooch, 2004).
Therefore, in order to promote the diffusion of biogas technology, it is necessary that the viability of these systems be established. Inadequate information about the economic viability of biogas energy production systems could be a hindrance to potential investment in this sector accounting for its dismal performance in Uganda. Socio-economic appraisal of the biogas technology needs to be undertaken to determine its adoptability, functionality and potential (Yadvika, 2004).

To obtain an appropriate strategy to overcome the barriers and the problems in the adoption of biogas technologies, the current situation of household energy perceptions and preferences needs to be investigated (Limmeechokchai and Chawana, 2005) because any attempt to shift households to better quality fuels requires an understanding of the factors determining the current choice of fuels (Gupta and Ravindranath, 1997). Thus, a greater understanding of why households have not sufficiently explored biogas energy source option is crucial. This is because unless the energy option is well accepted by society, it has little chance of successful implementation regardless of its technical and economic merits. Economic incentives (or disincentives), although important, are not the only driving force behind adoption of a given technology (Sterner and Bartelings, 1999; Akinbami et al., 2001).

Household fuel choice also depends on other factors, which makes knowledge of other determinants of households' choice of fuel important (Mekonnen and Köhlin, 2008). An assessment of energy use perceptions and preferences of households in Uganda could help to explain why the biogas technology has taken long to be adopted. In complex situations with multiple stakeholders having varied interests in the decision-making process, it is impossible to make a good decision simply based upon tangible efficiency i.e. economic utilization and technological practicability alone (Sohn, et al., 2001). It also heavily depends on acceptability of the outcome to the various stakeholders. Thus, the perceptions of households involved in the decision process need to be well understood in order to come up with a policy-mix for sustainable production and utilization of biogas in Uganda.

1.6 Scope and limitations of the study

Uptake of a given technology is influenced by both technical and non-technical attributes of the technology. This study focused mainly on the socio-economic factors that influence the production and utilization of biogas energy from family sized digesters in Uganda.

The study specifically assessed biogas energy from fixed dome digesters with the use of cowdung as feedstock. There are other types of family-sized digesters, that is, the floating drum and plastic bag family-sized digesters. Biogas energy can also be generated from other feedstock such as industrial waste, crop residues and household waste. This study did not include biogas energy production and utilization from other sources of feedstock neither did it consider other family-sized digesters.

The study also relied on primary and secondary data as the major sources of information. This thus called for use of estimates and in certain cases proxies for some variables. The results of the study therefore need to be understood and treated in this context, and therefore be regarded as indicative, rather than being considered definitive and exhaustive. In other words, while the findings of the study could be extended to other areas with similar socio-economic conditions with some adjustments, generalizations to wider areas and larger scales should be done with precaution. Supplementation of the results with further studies is highly recommended because of the differences and peculiarity of specific areas.

1.7 Structure of the thesis

This thesis is organized in five sections. Apart from the Introduction, which is Section one, Section two reviewed the literature in the field of technology adoption and socio-economic evaluation of biogas energy from family-sized digesters. Section three provides the methodological approach adopted for the study, while results and discussion are presented in section 4. Finally, the conclusions, contributions of the thesis and suggestions for further research are provided in section five.

CHAPTER TWO

2.0 LITERATURE REVIEW

This section gives the conceptual framework of the study and reviews some of the similar studies that have been conducted on biogas energy production and utilization and other related aspects to this study.

2.1 Theoretical Framework of the study

The basic economic principles underlying this study stem from economic theory that attempts to estimate the economic value that individuals or households place on various goods, services and public programmes. The welfare implications resulting from households consuming a given good or service are often expressed in an index measured in monetary amounts which would need to be taken or given to the agent to keep the agent's overall utility constant.

In this study, it is assumed that households know their major energy problems and can state their preference among the available alternative technologies for addressing this problem. This assumption is based on the stated preference theory of the household's implicit cost and benefit expectation from the alternative interventions, given their resource endowment. Households are expected to rationally reveal their preference in line with the objective of improving their welfare. This preference can be expressed by a utility function and the decision problem can, therefore, be modelled as utility maximization problem (Bekele, 2003).Based on the assumption that the only information available is the ordering of alternative situations (preference map) by the household, the principle of welfare measurement of individual households can then be derived (Bekele, 2003). Observations of households' preference among the different interventions can reveal the households' ranking of alternatives. Suppose that the household derives utility from choosing a given technology or option given his resource endowment. Let the choice of a given technology be represented by *k,* where *k* = 1, if the household is willing to choose a given technology and *k = 0*, otherwise. Resource endowment of the household is represented by *r*, and the vector z represents other observable attributes of the household that might potentially affect the desirability of the intervention technology being proposed. If the household prefers the proposed technology, its utility will be given by:

$U_1 = U\ \ 1, r, z$, and

if he does not prefer the intervention,

$U_0 = U(0, r, z).$

From standard economic theory, households should choose the proposed technology intervention they like best (offering them the best utility), subject to their resource constraints. As it is common in the specification of utility functions, an additively separable utility function is assumed in the deterministic and stochastic components, where the deterministic component is assumed to be linear in the explanatory variables, i.e.

$$U_1 = U(1, r; z) = T(1, r; z) + \varepsilon_1 \quad (2.1)$$

and

$$U_0 = U(0, r; z) = T(0, r; z) + \varepsilon_0 \quad (2.2)$$

where U_j *(.)* is the utility from the proposed intervention technology, *T (.)* and ε_j are the deterministic and stochastic components, respectively, and the latter represents the component of utility known to the households but unobservable by the economic investigator. Households are assumed to know their resource endowment, *r*, and implicit cost of acquiring the technology in terms of resource needs of the technology, and can make a decision to invest on it or not. Let the households implicit cost of the technology be represented by *C*, a household will prefer the proposed technology if

$$U_1(.) \geq U_0(.)$$

$$T(1, r - C; z) + \varepsilon_1 \geq T(0, r; z) + \varepsilon_0 \qquad (2.3)$$

The presence of the random component allows us to make probabilistic statements about a decision maker's behaviour. If the household prefers the technology being proposed, the probability distribution is given by:

$$P_1 = \Pr(Yes) = \Pr(T(1, r - C; z) + \varepsilon_1 \geq T(0, r; z) + \varepsilon_0 \qquad (2.4)$$

and if the household does not prefer the technology:

$$P_0 = \Pr(no) = \Pr(T(0, r; z)) + \varepsilon_0 \geq \Pr(T(1, r - C; z)) + \varepsilon_1 \qquad (2.5)$$

With the assumption that the deterministic component of the utility function is linear in the explanatory variables, the utility function in (1.1) and (1.2) can be expressed as:

$$U_1 = \beta_1 X_i + \varepsilon_1$$

and $U_0 = \beta_0 X_i + \varepsilon_0$ respectively,

and the probabilities in equations (1.4) and (1.5) can be given as :

$$P_1 = \Pr(Yes) = \Pr(U_1(.) \geq U_0(.))$$

$$= U = \beta_1 X_i + \varepsilon_1 \geq \beta_0 X_i + \varepsilon_0$$

$$= \Pr(\beta_1' X_i - \beta_0' X_i \geq \varepsilon_0 - \varepsilon_1) \quad (2.6)$$

Extending this argument to multiple choice alternatives, suppose there is a choice between *L* different alternatives indexed by *k = 0 ....L* with an arbitrary ordering. Assume the utility the individual, *i*, attaches to each alternative is given by $U_{ik} = 1, 2 \ldots L$. The household will prefer alternative technology *k* if he expects to gain the highest utility from the use of that technology. That is:

$$U_{jk} = Max\{U_{i0},\ldots,U_{iL}\} \quad (2.7)$$

The probability that household *i* prefers the technology *k* from among *L* alternatives is given by:

$$P(S_i = k) = p\{U_{jk} = Max\{U_{i0},\ldots,U_{iL}\}\} \quad (2.8)$$

where S_i denotes choice of individual *i* (Bekele, 2003).

Since choices are inevitable, a criterion for judging the desirability of various technology options by the household becomes essential.

2.2 Anaerobic digestion technology

Many studies have been conducted on biogas production and utilization as an alternative energy resource. A similarity with most of these studies is the emphasis of the importance of biogas as a source of energy (Adeoti et al., 2000; Akinbami et al., 2001; Gupta and Ravindranath, 1996; Ni and Nyns, 1996; Singh and Sooch, 2004; Taleghani and Kia, 2004; Yadvika et al., 2004).

Biogas producing materials (substrates) range from animal dung to household, agricultural and industrial wastes. It is produced through the process of anaerobic decomposition and fermentation of cellulose containing biodegradable materials such as cattle dung, poultry droppings, pig excreta, human excreta, crop residues (Erdogdu, 2008). This results in the production of a combustible gas containing 40–70% methane, 30–40% carbon dioxide, 1–5% hydrogen and traces of nitrogen, hydrogen sulphide, oxygen, water vapours, etc (Erdogdu, 2008; Singh and Sooch, 2004). The structural set up in which the fermentation occurs is called the biogas plant - a technical facility in which the biogas production process takes place (Raven and Gregersen, 2005).

Biogas is utilized mainly for cooking and lighting while the slurry provides a good source of manure for soil fertility improvement. For operational biogas plants, households use the slurry as fertilizer for their crops, especially vegetables and fruits (Walekhwa et al., 2009). With proper location and construction of the biogas units, the slurry will freely flow downstream to gardens. Slurry occurs in the following common forms (1) a light and rather solid fraction, mainly straw or fibrous particles which float to the top of the digester forming a scum (2) a very liquid, watery fraction remaining in the middle layer of the digester (3) a viscous fraction below which is the real slurry or sludge, and (4) heavy solids, mainly sand and soil particles, which settle at the bottom of the digester.

2.3 Biogas plant designs

There are many designs or models of biogas plants. However, each design is directly linked to its hydraulic retention time (HRT), which may be defined as the time period during which the biogas producing material stays in the digester to produce the biogas before being fully exhausted of its biochemical potential of producing biogas (Singh and Sooch, 2004). The HRTs of plants are different for different regions. In tropical countries, HRT varies from 30–50 days while in temperate countries it may go up to 100 days (Yadvika, 2004).

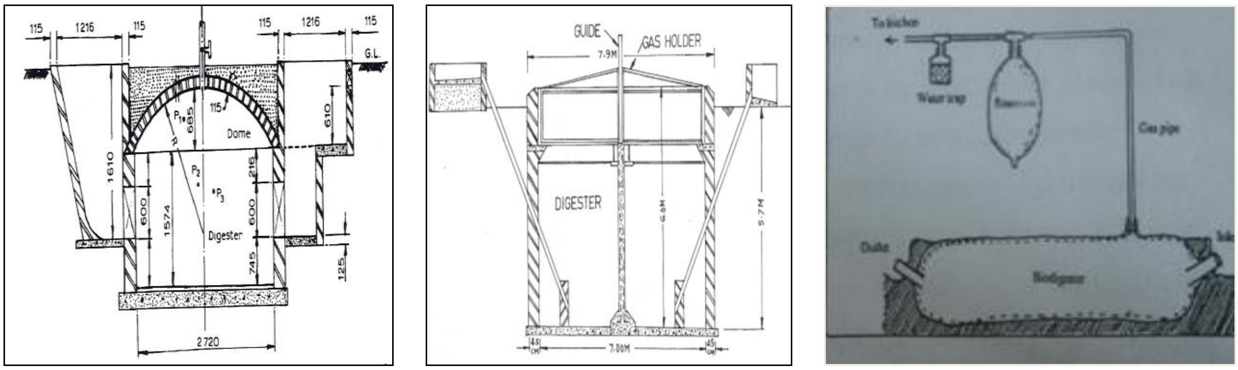
The models of biogas plants used in developing countries are mainly small-scale ones and are commonly referred to as family-size digesters (Singh and Sooch, 2004). There are two basic designs of family-size biogas plants; the floating drum type and fixed dome type . The floating drum type plants, which are Indian designed, have an underground well shaped digester with inlet and outlet connections through pipes at its bottom on either side of a partition wall (Rijal, 1985). An inverted drum (gas holder), is placed in the digester, which rests on the wedge shaped support and the guide frame at the level of the partition wall. This drum can move up and down along a guide pipe with the accumulation and disposal of gas, respectively. The weight of the drum applies pressure on the gas to make it flow through the pipeline to the point of use (Singh and Sooch, 2004).

Because of the need to have an alternative inexpensive design to bring it within the reach of the poor rural population, two types of fixed dome models of biogas plants, which are Chinese designed, have been designed (Kandpal et al., 1991). In this case the digester and the gas holder are integrated parts of the brick masonry structure and the digester is made of a shallow well having a dome shaped roof on it. The inlet and outlet chambers are connected with the digester through large chutes. These chambers are above the level of the junction of the dome and the cylindrical well. The gas pipe is fitted on the crown of the masonry dome.

The second model is designed on the basis of the principle of minimization of the surface area of a biogas plant to reduce its installation cost without sacrificing its functional efficiency (Singh and Sooch, 2004). The design consists of two spheres of different diameters, joined at their bases. The structure thus formed acts as the digester or fermentation chamber, as well as the gas storage chamber. The digester is connected with the inlet pipe and outlet tank. The upper part above the normal slurry level of the outlet tank is designed to accommodate the slurry to be displaced from the digester with the generation and accumulation of biogas.

2.4 Biogas plant designs in Uganda

The plant designs used in Uganda are mainly the small-scale type commonly referred to as family-sized digesters (Kandpal et al., 1991) with two basic designs: floating drum and fixed dome. The fixed dome is the most preferred biogas plant design in Uganda (Figure 1a and 2a). The floating drum digester is not popular because it is very costly (Figure 2b and 2b). The CAMARTEC digester, a fixed dome design modified by the Centre for Agricultural Mechanisation and Rural Technology (CAMARTEC), Tanzania, is the most common digester in Uganda. Its installation cost ranges between US$ 700 and 1200, depending on the size (Kassenga, 1997).



a) Fixed-dome biogas plant *(b) Floating-drum biogas plant* *(c) Tubular biogas plant*

Figure 1. Schematic representation of the family-sized biogas plants (Singh and Sooch, 2004).

Another type also referred to as the tubular or polythene or plastic digester (Figure 2a and 2c) has been recently promoted to reduce installation and operation costs further by using local materials.

(a) Fixed-dome biogas plant *(b) Floating-drum biogas plant* *(c) Tubular biogas plant*

Figure 2. Pictorial representation of the family-sized biogas plants in Uganda (Survey data, 2007).

The type of plastic materials needed for this digester can be obtained locally, and construction requires relatively simple skills, thereby significantly lowering costs (Kassenga, 1997). However, this type of digester is unpopular in Uganda because it has a much shorter lifespan than the other types (Walekhwa et al., 2009).

Most family-sized digesters promoted in Uganda have installed digester capacity volume of 8, 12 or 16 m^3 (Walekhwa et al., 2009). Few community and institutional biogas plants with capacity of 30 or 50 m^3 have also been installed. Cowdung for the zero-grazed cattle is currently the major feedstock for biogas digesters in Uganda (Figure 3). However, there is an abundance of other potential feedstock, including agro-industrial wastes and residues, municipal solid wastes and waste waters, forestry by-products and residues, crop residues and household food wastes (Walekhwa et al., 2009).

Figure 3. Zero grazed Cattle; the major source of substrate for the plants in Uganda (Survey data, 2007)

The biogas generated is for mainly household cooking and lighting while the slurry is used as a fertilizer in agricultural production (Figure 4).

(a) Beans being cooked on a biogas stove *(b) Lighting is a key benefit from biogas* *(c) Slurry: used as fertilizer for vanilla crop*

Figure 4. Biogas utilization in Uganda (Survey data, 2007)

2.5 Biogas energy production and utilization in other parts of the world

In Europe, crop and animal wastes are being used to generate biogas energy. This, to a great extent, has reduced environmental problems associated with crop and animal wastes (Raven and Gregersen, 2005). The European Union is producing more than four million tonnes of oil equivalent (MTOE) of biogas each year (Refocus Report, 2005). In these countries, biogas is produced from several different sources, mainly from waste storage centres (rubbish dumps) and urban and industrial sewage treatment plants, municipal dump methanisation units, agricultural installations and collective co-digestion units (Refocus Report, 2005).

Centralised biogas plants in Denmark, for instance, generate renewable energy, enable recycling of organic waste, play a role in manure distribution and storage, and improve the veterinary aspects of manure. These advantages make biogas plants a technology that is able to combine several environmental benefits across different sectors (Raven and Gregersen, 2005).

Similarly in Asia, biogas production is an important waste management strategy and a vital source of household energy. For instance, the biogas digester is a popular project as a waste treatment system in Thailand (Limmeechokchai and Chawana, 2005). China, the biggest rural biogas user in the world, already had 5.7 million operational rural household digesters by the end of 1995 for cooking and lighting and in some cases for electricity generation (Ni and Nyns, 1996). In India, 35,647 biogas plants had been installed in the state of Himachal Pradesh alone by 1995 **(**Singh and Verma, 1996). By 1994, an estimated 285 million tonnes of net animal waste generated between 10,830 and 21,660 million m^3 of biogas per year in Pakistan (Ghaffar, 1994). In Nepal, over 37,000 biogas plants were established between 1992 and 1996, serving over 200,000 people (Biswas and Lucas, 1996).

2.6 Biogas energy production and utilization in Uganda

While the foregoing biogas energy production and utilization statistics show that biogas technology is a successful story in Europe and a number of Asian countries, this important waste management strategy and renewable energy source has not been fully harnessed in Africa (Akinbami et al., 2001). The development of biogas technology in Eastern Africa is still at an embryonic stage although the potential is promising (Day et al., 1990; Mwakaje, 2008). Data on the number and size of biogas plants and actual quantity of biogas generated in various African countries remain scanty (Akinbami et al., 2001).

The history of biogas technology in Uganda is relatively old, dating back to the 1950s when the technology was first introduced by the Church Missionary Society (Nabuma and Okure, 2004; Pandey et al., 2007). In the 1960s some missionaries built one demonstration plant in Kotido district. The first extensively documented study on biogas technology in the country was a PhD thesis by Boshoff then based at Makerere University (Pandey et.al 2007). He studied the biogas digester built at Kabanyolo University Farm for demonstration purposes. However, the technology did not go beyond the University farm gates.

Pandey et al. (2007) further assert that a baseline study of biogas technology in the central region of Uganda was conducted and recommended that biogas energy in Uganda was viable. However, implementation was not undertaken due to poor political climate at the time. Since then, there have been efforts by the government to promote the technology but with limited success. In 1985, a Chinese biogas technical team carried out a feasibility study covering many districts in Uganda including private, government and co-operative firms (Pandey et al., 2007). They concluded that the technology was most viable in small-scale private dairy farms with easy access to feedstock. A government pilot project was implemented by the then Ministry of Animal Husbandry and Fisheries with technical assistance from the Republic of China, in which seven digesters were installed in Eastern Uganda in 1985 (Kuteesakwe, 2001). However, because of inadequate technical capacity to monitor and maintain the digesters, only one digester was functional by 1987. Another Programme funded by the World Bank and implemented by the then Ministry of Natural Resources established 10 biogas digesters with a total gas capacity of 262 cubic meters. This programme did not also register much success.

In 1989, the government showed further interest in the technology, and several demonstration plants were constructed in the country (Pandey et al. 2007). FAO carried out another study through the then Ministry of Energy, which led to the creation of a National Biogas Programme in Uganda. They recommended that the Chinese-type design be built in secondary schools as bio-latrine system using cow dung but with possibilities of incorporating human waste later. A number of secondary schools consequently built these plants such as Tororo Girls' secondary school, Kings College Budo, Busoga College Mwiri, Namagunga and Gayaza High school. Most of these schools did not have adequate livestock. The acquisition of feedstock became the main constraint coupled with inadequate knowledge of the technology (Kuteesakwe, 2001).

During the 1990s, a number of government and private initiatives were invested in development and popularization of biogas technology in Uganda. Between 1997 and 1998, the Chinese Government, through a memorandum of understanding with the Government of Uganda, committed about US$ 170,000 for construction of 20 demonstration biogas digesters and training of Ugandans in the design, construction and maintenance (Kamese, 2004). During this period an estimated 120-170 biogas units were constructed in the country. Out of these, about 50% were operational by 1999 (Kuteesakwe, 2001). Several demonstration biogas plants were built over a decade ago but the technology never went beyond the demonstration sites. All these programmes demonstrate the government's attempts through funding from various donor agencies and private initiatives to disseminate biogas technology in the country.

Biogas energy has been recently popularised mainly by nongovernmental organisations (NGOs) including Heifer Project International (HPI), Adventist Relief Agencies (ADRA), AMREF and Africa 2000 Network. Smaller technologies that do not require a lot of investment in costs of construction were introduced and are being promoted mainly by NGOs to boost dissemination of biogas technology in the country. In general, the development of biogas technology in Uganda has not been very significant. Pandey et al., (2007) assert that the total theoretical biogas potential is about one billion m^3 per year, with energy potential equivalent to a 1,000 MW hydropower plant.

2.7 Technology adoption decision analysis

Technological innovations from research stations need to be adopted by the intended end-users if they are to create the desired impact. For decades, it is the belief that the adoption process is a one-way progression from research to extension to adoption (Cramb, 2003). Many programmes aimed at promoting a given technology have therefore tended to focus more on the technical aspects of the technology disseminated. However, the adoption decision process still remains a complex multidimensional construct because there is no clear-cut defined way through which adoption of technologies proceeds. Thus, while some new technologies are highly adopted, others continue to register low adoption rates.

Two theories that have dominated adoption studies include the innovation-diffusion theory and the economic constraint theory (Adesina and Zinnah, 1993). The innovation-diffusion model asserts that the availability and communication to potential users of information about an innovation is the key factor in determining adoption decisions. Most adoption studies have focused on this approach (Masangano and Miles, 2004) as a way of increasing technology adoption rates. The economic constraint theory contends that the distribution of resource endowments among the potential users determines the pattern of adoption of a technological innovation (Mekonnen and Köhlin, 2008). Many studies on adoption have therefore modelled the socio-economic and demographic characteristics of technology users as the key determinants of the adoption decision process (Kebede et al., 1990; Fleke and Zegeye, 2006; Mendola, 2007) often concluding that the observed adoption choice for an innovation is the result of a complex set of interactions between comparable technologies and the user's socio-economic and demographic characteristics (Somda et al., 2002).

More recently, the adopter-perceptions theory contends that in real life, people consider many attributes in selecting a given technology and the justification involves decisions requiring analysis of a large number of tangible and intangible attributes of the technology in a decision support environment (Chan et al., 2000). They assert that consumers generally have subjective preferences for characteristics of products and that their demand for a particular product is significantly affected by their perceptions of product attributes (Adesina and Baidu-Forson, 1995). Sinja et al. (2004) assert that users interface directly with the technologies and their perceptions of the technology characteristics could have a significant effect on its adoption rates. They contend that users will reject that technology not suited to their work environment and that which might interfere with other activities considered more important.

Proponents of the adopter-perceptions theory assert that technology users are often not given reasonable opportunities for comparisons and deliberation on alternative technologies intended for them. As a result, user perceptions on various technological innovation options are often largely overlooked which generates distrust in the technology being promoted; affecting its adoption rates (de Steiguer et al., 2003). There is heavy reliance on research experts in deciding technology options for the public. Given the complex set of factors influencing adoption decisions, expert-based ex ante estimates of technology adoption may lead to unrealistic and biased assessments (Batz et al., 2003). This has led to the realization that the adoption process is not only affected by the technological characteristics of the technology, but also the socio-economic and behavioural attributes of the technology user. This shift in the adoption paradigms is evidenced from the ever increasing literature on factors affecting adoption of new technologies in recent decades.

2.8 Socio-economic evaluation of biogas energy production and utilization

Literature on consumers' decision behaviour has succeeded in revealing the complexity of factors involved in the adoption process with each study only adding to the existing body of knowledge in the area by identifying new variables to be considered in the behavioural function (Bekele, 2003). The complexity arises from location-specific nature of the problem and the diversity of consumers' circumstances that make it difficult to draw some reasonable generalization. These differences often stem from the variation in agro-ecological, socio-economic and institutional factors among countries, regions, villages or even households.

2.8.1 Econometric Models used in adoption studies

The most commonly used econometric models in adoption studies are the limited dependent variable models such as logit and probit (Bekele and Drake, 2003) and both are well established approaches in studies on technology adoption (Burton et al., 1999). The choice of whether to use a probit or logit model, both widely used in economics, is a matter of computational convenience (Greene, 1997). Logistic regression is used when the dependent variable is a dichotomy and the independent variables are of any type. It applies maximum likelihood estimation after transforming the dependent into a logit variable (Garson, 2008). The basic assumption underlying such discrete choice theory is that consumers rationally choose from a number of alternatives and select that with the highest utility level. The assumption is that households rank collections of technology indirectly through the characteristics they possess and that a given technology embodies a number of characteristics that influence adoption decisions.

The variables often considered in biogas energy adoptions decision include age, educational status, income level, household size, gender of the household head, size of land owned by the household and the cost of alternative fuels (Somda et al., 2002). However, explanatory variables used in the adoption process have often lacked a firm theoretical basis, possibly due to the fact that households consider a variety of other issues beyond socio-economic incentives, including non-economic factors (Kebede et al., 1990). The development and management of biogas technology are far from a purely technical question and almost always involve economic and social problems and human behaviour characteristics (Mendola, 2007).

Considerable amount of existing literature on adoption behaviour concurs that social, personal, physical, economic and institutional factors are key determinants of the adoption process (Adesina and Baidu-Forson, 1995; Drake et al., 1999; Kassenga, 1997; Somda et al., 2002; Bekele and Drake, 2003). Some of the research findings that give an overview of the factors influencing biogas technology adoption in developing countries include Adesina and Baidu-Forson (1995); Adesina and Zinnah (1993); Akinbami et al. (2001); Amigun and von Blottnitz (2007); Karekezi (2002); Kebede et al. (1990); Mwakaje (2007); Ni and Nyns (1996); Pandey et al. (2007); Somda et al. (2002); Walekhwa et al. (2009). As reported in these studies, the income of the household, household size, land size holdings, educational status of the household head, cattle herd size and the price of alternative fuels generally influence biogas technology adoption decision positively. However, the importance and direction of influence of different variables will vary depending on the different socio-economic conditions and sites.

Literature on factors influencing the adoption and development of biogas energy has increased in the recent past highlighting technical, organisational and economic factors as critical (Adeoti et al., 2000; Ni and Nyns, 1996; Walekhwa et al., 2009). Singh and Sooch (2004), in their comparative study of different biogas plant models in India, underscored the importance of determining economic viability of family size biogas plants as a vital ingredient in the development of biogas technology. Srinivasan (2008) observed that domestic biogas programs are often justified on the basis of the private benefits and costs accruing to the individual households. However, the economic surpluses from domestic biogas programs are realized beyond such narrowly defined project boundaries.

This implies that the total benefits accruing from the installation of biogas plants exceed the benefits to the individual who invests in, receives or runs the service. Society is perhaps, likely to benefit more than the individual recipient does (Srinivasan, 2008).

Hall et al. (1992) assert that a number of developing countries could adapt and improve the technologies for modern bio-fuels but the contentious problems are with economics. Taleghani and Kia (2004), in their technical–economical analysis of the Saveh biogas power plant in Iran indicated that there were several economic benefits from using biogas plant. These included treatment of solid waste, reduction of foreign exchange needs and generation of income, improved soil/agricultural productivity and recovery of material for the recycling industry. However, they noted that environmental benefits to the society were hard to quantify economically. Akinbami et al. (2001) used a three scenario analysis to examine the future prospects of biogas in Nigeria. Results showed that high capital investment cost, type of design and materials for building the plant and socio–cultural factors like low level of literacy were potential barriers to the adoption and dissemination of biogas technology in Nigeria. Adeoti et al. (2000), recognize that the development and utilization of biogas technology remained unpopular in Nigeria, partly because of lack of information on its economic viability.

Raven and Gregaseen (2005) identified three factors that were important for the success of biogas plants in Denmark. These were the bottom-up strategy applied by the Danish government that stimulated interaction and learning between various social groups. Second, a dedicated social network enabled a continuous development of biogas plants without interruptions, and third, specific local circumstances.

Prasertsan and Sajjakulnukit (2005) recommended some measures to promote biogas and other renewable energy sources in Thailand; devise incentive measures encouraging purchase of power generated by renewable energy, for example, provision of tax credit, privilege, and subsidies from the Energy Conservation Promotion Fund, support research and development on renewable energy such as biomass (agricultural wastes and municipal wastes), and encourage participation and partnership of the local communities in renewable energy fuelled power plants. Ni and Nyns (1996), while studying the effect of individual economic status on adoption of biogas technology, assert that biogas is more easily accepted by upper and middle-income farmers. They add that a survey in seven Asian and African countries by GTZ in 1987 indicated that among 610 adopters of biogas, only about 5% were relatively low-income farmers. They also note that the regular operation of a biogas plant is more difficult to achieve than its initial installation. This highlights the importance of proper management of the biogas plant in the success of biogas production and utilization.

Literature shows that, in many cases, non-technical reasons, including the loss of interest by the digester/owner, are the main causes that lead to the failure of continuous digester operation (Ni and Nyns, 1996). Some studies have also shown that at the local community level, the availability and price of the traditional and conventional energy are the decisive part of adoption of biogas technology when its main purpose is to obtain energy (Biswas and Lucas, 1997; Kandpal et al., 1991). Similar conclusions can be drawn when the benefits of the digester are not only focused on the biogas but also on bio-fertilizer or other products. This means that at the local, regional or community level, the right selection of the location for the biogas plant is very important.

Abort and Vancil (1977) contended that little has been published on the economic viability of biogas recovery systems because it is not known with certainty (1) exactly what percentage of waste refuse used in the recovery systems is of potential use; (2) how much of it can be recovered; or (3) what its market value will be after the recovery process. They further argue that each resource recovery plant location presents a different set of economic and operational parameters that must be defined and that the accuracy of these estimates determines the prospects for success of a particular waste recovery facility. These studies generally affirm that adoption of biogas technology is influenced by a number of socio-economic factors.

Standard analyses of economic viability of biogas energy production systems tend to emphasize primarily on direct financial costs and benefits associated with biogas production (Yiridoe et al., 2009). However, it is advisable that when considering the feasibility of biogas plants, non-economic factors also be considered (CAEEDAC, 1999). The overall economic evaluation of the viability of biogas energy production model is undertaken by use of economic decision criteria commonly used to evaluate the viability of alternative investment opportunities, including net present value, internal rate of return and payback period (Yiridoe et al., 2009). This is important to take care of both tangible and intangible benefits of biogas systems (Adeoti et al., 2000). While all the likely tangible benefits are normally taken into account in financial evaluation, the intangible benefits such as additional benefits in terms of incremental fertilizer saving are often invariably not considered in the analysis rendering such evaluations incomplete (Purohit and Kandpal, 2007).

This study takes care of this omission by use of different economic decision criteria. The different decision criteria need to be used in the analysis because they consider different (but complementary) attributes of economic viability of the biogas system being evaluated. Consistent results from the different decision criteria help to improve the robustness of the analysis, as well as increase confidence in the viability of the investment opportunity (Odeh et al., 2006). Other studies that used these criteria to assess the financial feasibility of on-farm biogas energy projects include Adeoti et al. (2000); Caputo et al. (2005); Odeh et al. (2006); and Yiridoe et al. (2009).

Sensitivity analysis using estimated economic values (costs and benefits) is often undertaken to incorporate uncertainty into the economic evaluation. There are many assumptions and uncertainties involved in the cost benefit analysis. The parameters may vary due to location (such as the price of fuel wood, interest rates), technology development (such as the change of lifetime biogas plants: improvement of cooking stove efficiency) and various other factors (Kandpal et al., 1991). Sensitivity analysis is used to generalize the results for different situations where input parameters and costs differ (Odeh et al., 2006) and explores the net effect on the net present cost of the systematic changes in individual parameters (Wilson, 1979).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Description of the study area

The study sites were Luwero, Nakaseke and Nakasongola districts in Central Uganda, and Mbale, Sironko and Manafwa districts in Eastern Uganda [1](Figure 5).

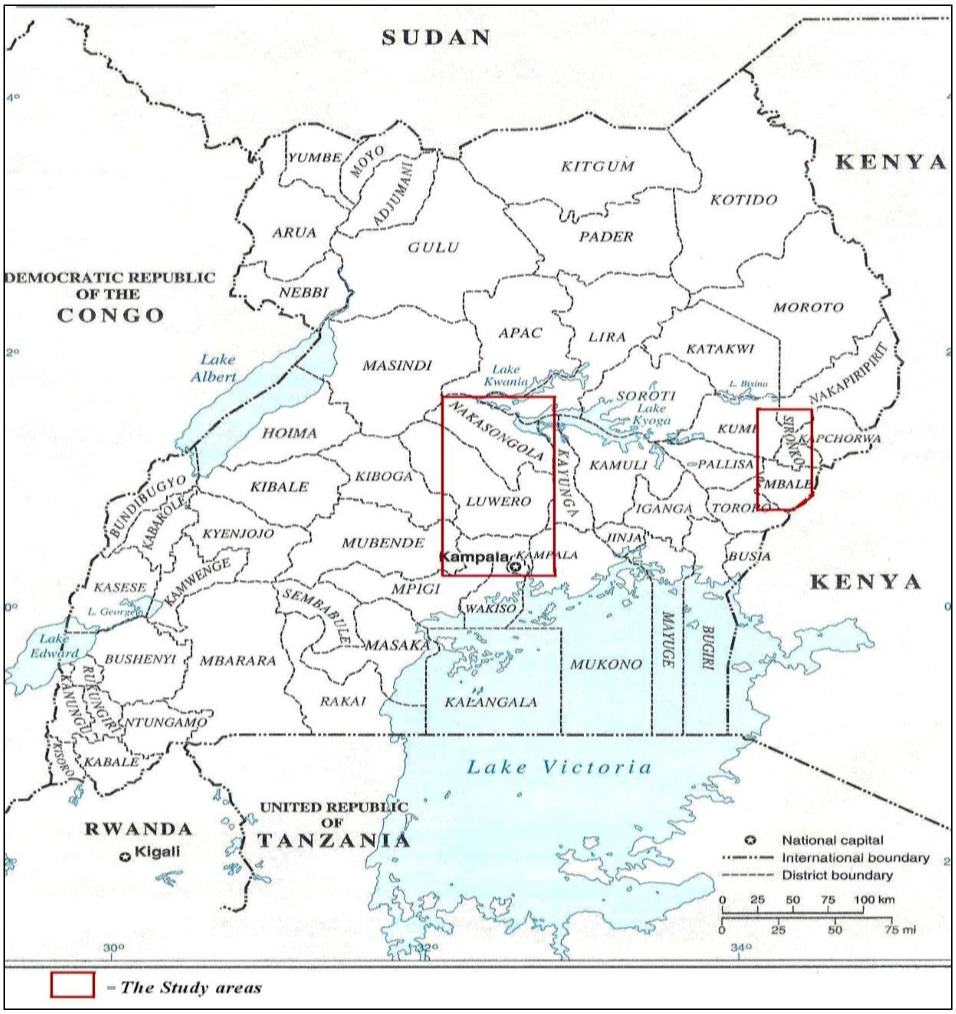


Figure 5. Map of Uganda showing the study areas (MFPED, 2002)

[1] Luwero ($0^0$57'36.11"N $32^0$15'55.40"E), Nakaseke ($1^0$31'30.32"N $32^0$04'33.88"E), Nakasongola ($1^0$19'31.48"N $32^0$27'17.65"E), Mbale ($1^0$4'50.56"N $34^0$10'02.75"E), Sironko ($1^0$13'48.96"N $34^0$14'46.78"E) and Manafwa ($0^0$54'40.30"N $34^0$22'22.65"E).

These districts, especially those in Eastern Uganda, are relatively densely populated with approximately 133 persons per square kilometre (MFPED, 2002). Subsistence agriculture remains the dominant economic activity on heavily fragmented land holdings. Fuelwood is the most important energy source for cooking and kerosene for lighting purposes. Charcoal burning is also an important economic activity. Given the high population density coupled with high dependence on fuelwood as the major energy source, deforestation and other forms of environmental degradation are an eminent threat. With the limited landholdings, intensive agricultural production systems (especially confined animal feeding operations) and ecology friendly energy sources like biogas are being proposed as most suitable.

3.2 Sampling Procedure and Sample size

Five districts in the two regions were purposively selected for this study. These included Nakasongola, Wakiso, Mukono, Nakaseke and Luwero in the Central Region and Mbale, Sironko, Manafwa, Tororo and Kapchorwa in Eastern Region. These districts were selected because they had been specifically targeted by NGOs promoting biogas technology. They were also identified as districts with the highest concentration of households with zero-grazing dairy farming units. In Uganda, cow dung was the major feedstock for biodigesters at the time of the study and it was hoped that the potential of adopting biogas technology in areas with adequate supplies of raw materials would be higher in these regions than in other parts of the country. Three districts in each region were then randomly selected bringing the total number of districts studied to six, that is, Luwero, Nakaseke and Nakasongola districts in Central Region, and Mbale, Sironko and Manafwa districts in Eastern Region.

The sample included both households with biogas units and those without. In each district, the sampling frame for households with biogas units, hereafter referred to as biogas users or simply users, was obtained from the NGOs promoting biogas technology in the area, while that for households without biogas units, hereafter referred to as biogas non-users or simply non-users, was obtained from the Village Local Council offices. Fifty households per district in each category were randomly sampled and a total of six hundred households were selected. Stratified sampling was then used to choose 25 biogas users and 50 non-users from each district. A total of 150 biogas users and 300 non-users formed the final sample for the study. Thus, the sampling method could not be based entirely on a random selection because the number of biogas users in relation to the nonusers in the study area was too small and no complete list of biogas users was available from which a random sample could be drawn. After thorough data cleaning, a final sample of 100 biogas users and 150 non-users formed the basis of this analysis.

3.3 Data collection Methods

This study was based on household surveys conducted between 2007 and 2009. Fieldwork was conducted mainly through open-ended interviews and self-administered questionnaires by households. The interviews were combined with simple Participatory Rural Appraisal (PRA) tools because these have been well known to facilitate quick acquisition of information. Prior to the surveys, reconnaissance visits to the study sites were conducted and focus group discussions (FGDs) held with households and key informants to develop the interview guides for the survey and to ascertain the sampling frames obtained.

Primary data collected included socio-economic and demographic characteristics of households (age and educational status of household head, experience of household in biogas production and use, household size), household perceptions of biogas technology, and detailed financial biogas plants installation and operational costs and benefits. Supplementary data (mainly secondary) were obtained from other key stakeholders in the biogas industry in Uganda mainly the line ministries and NGOs, biogas technicians and equipment suppliers engaged in the promotion of biogas technology.

3.4 Data Analysis

Data were analysed using statistical techniques, (principally descriptive statistics used to identify the general pattern and trends in the data, cross tabulations, frequency tables, logistic and Tobit regressions) with the aid of the Statistical Package for Social Scientists (SPSSv12) and STATA v9 computer softwares.

3.4.1 Socio-economic factors influencing biogas energy production and utilization

There are a number of factors why biogas technology has not been fully embraced in Uganda despite the numerous advantages and demonstrated experiences as a good waste management strategy and renewable energy source. Household income levels might not be the only major factor or consideration for investment in biogas technology. Socio-economic and institutional factors operating from the level of the national economy through the individual households all play an important role in influencing household decisions to invest in biogas technology.

Factors operating at the national level are crucial in influencing household decisions by providing incentives and a favourable environment that could attract individual households to invest in biogas energy production and utilization. This objective focuses on critical factors that influence biogas production and utilization by households.

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

$$\ln\left(\frac{P}{1-P}\right) = a + bX$$

$$P = \frac{e^{a+bX}}{1+e^{a+bX}} \qquad (3.1)$$

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

$$\Pr Y = \frac{1}{1+e^{-(a+bX)}} \qquad (3.2)$$

Y is the logit for the dependent variable. The logistic prediction equation for the present study was:

Y = ln(odds(event)) = ln(prob(event)/prob(nonevent) = ln(prob(event/[1-prob(event)])

$$= b_0 + b_1 X_1 + b_2 X_2 + \ldots\ldots + b_n X_n \qquad (3.3)$$

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

3.4.1.1 Variables explaining adoption of biogas energy

It was expected that socio-economic and demographic characteristics of households would be critical in the biogas technology adoption process. Adoption in this study was defined as the production and use of biogas energy from a family-sized biodigester by a household. Various factors affect the adoption process. Explanatory variables used in the adoption process have often lacked a firm theoretical basis, possibly due to the fact that farmers consider a variety of other issues beyond socio-economic incentives, including non-economic factors. The considerable amount of existing literature on adoption behaviour concurs that social, personal, physical, economic and institutional factors are key determinants of the adoption process (Adesina and Baidu-Forson, 1995; Drake, et al., 1999; Kassenga, 1997; Somda et al., 2002; Bekele and Drake, 2003). The full list of selected determinants of biogas adoption generated from the data set and their definitions are presented in Table 1.

Table 1. Definition of explanatory variables for biogas energy adoption in Uganda

Variable	*Type*	*Description*
AGEHHD	Continuous	Age of household head in years
EDUCHHD	Continuous	Formal education of household head in years
SIZEHHD	Continuous	Household size; total number of people in the household
LANDSIZE	Continuous	Total area of land owned by the household in acres
LVSTOCK	Continuous	Total number of cattle owned by the household
FWDCOST	Continuous	Household daily fuelwood cost for cooking purposes in Uganda shillings
KERCOST	Continuous	Household monthly kerosene cost for lighting purposes in Uganda shillings
SEXHHD	Binary	Gender of household head; a proxy variable for gender relations; (1 = Male; 2 = Female)
LOCHHD	Categorical	Location of the household; (1 = Rural; 2 = Urban)
INCOMHHD	Categorical	Total monthly household income in Uganda shillings[1] (USh); (1 = < 500,000; 2 = 500,000 - 1,000,000; 3 = > 1,000,000)

[1]Exchange rate 1USD = USh1700

Explanatory variables used in the model with their *a priori* signs are presented in Table 2.

Age of household head was expected to have a positive or negative influence on the decision to adopt biogas technology. Old age can be equated with higher economic status and therefore greater ability to afford a biogas plant. On the other hand, older people are less likely to accept innovation.

Table 2. Explanatory variables with a priori signs for biogas energy adoption in Uganda

Variable	*Expected sign*
Household size	±
Age of household head	±
Gender of household head	±
Household location	±
Total monthly household income	+
Formal education of household head	+
Total area of land owned by the household	+
Total number of cattle owned by the household	+
Household daily fuelwood cost for cooking purposes	+
Household monthly kerosene cost for lighting purposes	+

The old people are more risk-averse and not ready to experiment on new ideas. Adesina and Baidu-Forson (1995) claim that the expected signs of age are an empirical question because whereas older farmers have experience and are better able to assess the characteristics of modern technology than young farmers, older farmers may be more risk-averse than younger and have a lower likelihood of adopting new technology. The association between age and adoption of new technologies is sensitive to variation in parameters and therefore the net effect of age on adoption cannot be determined *a priori* (Bekele and Drake, 2003).

Formal education of household head was expected to have a positive influence in decisions on biogas energy. More educated household heads were expected to be less conservative, more exposed to sources of information and therefore more informed, knowledgeable and environmentally alert about the negative effects of fossil fuels on the environment. They should accept cleaner energy sources such as biogas on the grounds that it is more environmentally friendly more readily than their less educated counterparts.

Size of household was expected to influence the adoption decision either positively or negatively. A large family often has a large number of working members and thus more labour for routine biogas operation and maintenance activities. Therefore the larger the family, other things being constant, the higher the probability of adopting biogas energy. However, a larger family could exert a heavier burden of dependence on the meagre family resources to the extent that there are hardly any savings available for investment in biogas production. Under these circumstances, larger household size would negatively influence the decision to adopt biogas technology. An observation made by Kebede et al. (1990) was that if relatives are viewed as source of additional help, then the farmer may try new practices. However, if they are viewed as dependents, then the household head may not be willing to adopt a new technology.

Gender of household head was expected to have either a positive or negative effect. Since women dominate rural energy use at house household level (Karekezi, 2002), it can be expected that households headed by women could have a higher probability of adopting biogas energy than their male counterparts.

However, in Uganda, men dominate control, access, ownership and decision-making processes regarding productive resources in the household and could directly influence investment decisions regarding biogas technology.

Land area owned by the household was expected to have a positive effect on the decision to adopt biogas. For a biogas unit to run effectively and efficiently, all three components (biodigester, animal unit and fodder component) need to be close to each other for easy provision of feedstock to the biodigester and effective monitoring of routine operational and maintenance activities. For this to occur, a household must have a minimum land area threshold that can accommodate them. Based on this premise, it can therefore be expected that households with larger land acreage would have a higher probability of adopting biogas technology. Both theoretical and empirical studies of adoption show a positive association between farm size and the probability and extent of adoption (Brush and Taylor, 1992).

The number of cattle owned by a household is a key factor in the biogas adoption process because they provide cow dung, the major substrate for family-sized digesters in Uganda. The number of cattle owned by the household was therefore used as an indicator of the availability of feedstock for the digesters. It was expected that the greater the number of cattle owned, the higher the probability of the household adopting biogas technology.

Location of the household can influence the decision to adopt biogas energy either positively or negatively. If the household is located in a rural area where there is adequate space, the probability of adopting biogas energy could be greater than in urban centres where land shortage is acute. On the other hand, location influences the household’s access to crucial services, such as financial, credit, insurance and vital information services needed to implement new technologies. This could have a significant impact on the household’s decision to adopt a given technology including biogas energy. Because of this consideration, it can be expected that early adopters of biogas technology are those closer to administrative and urban centres than their counterparts in rural areas.

Technology uptake is driven by household income. Households with higher income levels were expected to adopt biogas technology more readily than their poorer counterparts. Household income was thus expected to carry a positive sign. The cost of major traditional fuels for cooking and lighting purposes, such as fuelwood and kerosene, was expected to be positively correlated with the probability of adopting biogas energy. Evidence from similar adoption studies indicates that the biogas digester is more attractive when the local equivalent energy price is high and the new technology has good characteristics such as high efficiency and ease of management (Ji-Quin and Nyns, 1996). Both variables are thus expected to have positive signs.

3.4.2 Household perceptions of biogas energy in Uganda

At the individual household level, factors which relate to the technical attributes of the technology and socio-demographic characteristics of the household influence technology use decisions. The second objective of this study evaluates the effect of these attributes on technology adoption decisions. To assess the key household user perceptions of and preferences for biogas energy in Uganda biogas user perceptions regarding selected characteristics of the Biogas Cooking Stove (BCS) relative to conventional cooking devices (CCDs) were sought (Figure. 6). The BCS was particularly the subject of considerable promotional efforts in a bid to diversify cooking energy sources in Uganda. The most common CCDs that complemented the BCS in the region at the time of the study were firewood, charcoal or kerosene stoves and, to a small extent, electric stoves.

Following Pohekar and Ramachandran (2006), technology (BCS) characteristics were broadly categorized into technical, economic, environmental, commercial, social and behavioural aspects. From each of the broad categories, with the help of FDGs, all the technology characteristics as specified by Pohekar and Ramachandran (2006) were ranked according to order of importance and the most important technology attribute was selected and used in this analysis. The selected characteristics and their significance are shown in Table 3.

Only one best ranked characteristic from each of the six perception characteristics classification categories was included in the analysis in order to cater for a reasonable number of variables that could allow for meaningful econometric modelling and interpretation and to get user perceptions on the various aspects of the technology. While eliciting user perceptions, households were asked to compare the BCS with the CCDs and rank it on a five-point scale as: 5 = Excellent, 4 = Very good, 3 = Good, 2 = Satisfactory and 1= Poor for each of the selected characteristics. The responses were later re-coded as: 1 = BCS as perceived as being superior to CCDs and 0 = Otherwise.

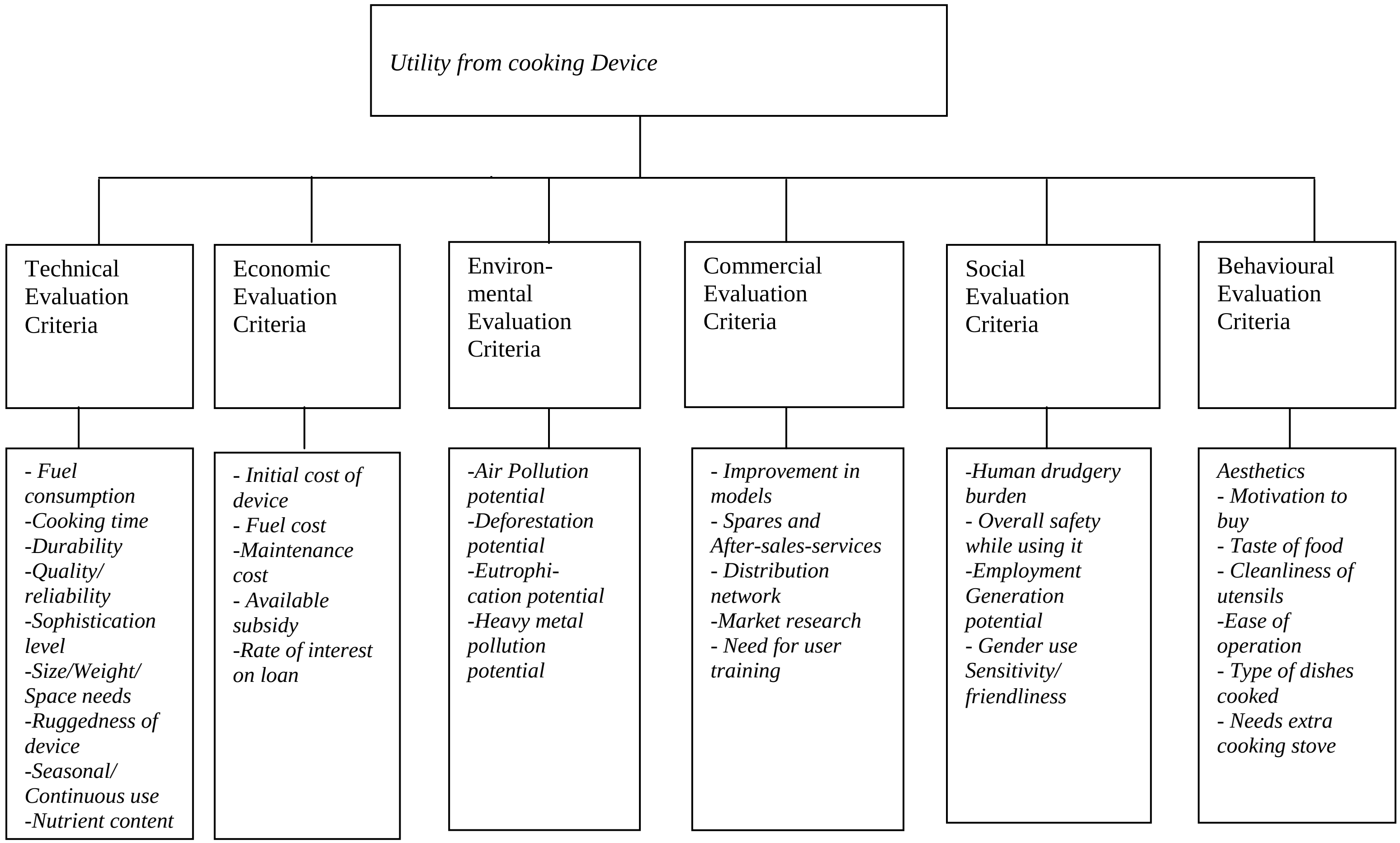


Figure 6. Criteria for evaluating utility from cooking devices (Pohekar and Ramachandran, 2006).

Table 3. Selected characteristics of Biogas Cooking Stove on which user perceptions were elicited

Category	***Desired value***	***Characteristics of the cooking device***	***Significance of characteristic in choice of cooking device***
Technical	High	Durability of cooking device	Increased reliability Reduced cost of replacement
Economic	Low	Initial cost of cooking device	Easy commercialisation Higher motivation to use
Environmental	Low	Air pollution impact of using cooking device	Increased social utility Higher motivation to use
Commercial	Low	Need for spares and after-sales service for cooking device	Increased reliability Easy commercialisation Low maintenance costs
Social	Low	Human drudgery burden imposed by cooking device	Increased productive time for household Increased social utility
Behavioural	High	Taste of food prepared with cooking device	Increased suitability Increased social utility

To conceptualise the effects of household perceptions on adoption decisions, aspects of characteristics models and on the theory of utility maximisation guided the study. Characteristics models postulate that households choose technologies based on the bundle of observable characteristics that each technology embodies and produces, rather than on the technology itself. Following Adesina and Zinnah (1993), the technologies were denoted as k_i, where $k = 1$ for the new technology being promoted (BCS) and $k = 0$ for the old technology (CCDs). When each technology is thought of as a possible adoption decision by the household, the household is expected to choose the technology that has higher expected utility among the alternatives considered (Bekele and Drake, 2003). The non-observable underlying utility function which ranks the preference of the i^{th} household is given by $U(T_{ki}, P_{ki})$. Thus, the utility derivable from consuming given energy technologies is a function of *T*, which is a vector of household-specific attributes, and *P*, a vector of the technology-specific attributes.

The adoption of the BCS is therefore modelled as a choice between two alternatives; the traditional technology (CCDs) and the new technology (BCS) (Fleke and Zegeye, 2006). Although the utility function is unobserved, the relationship between the utility derivable from a k^{th} technology is assumed to be a function of the vector of observed farm household-specific characteristics (e.g. household size, gender, experience of household head, etc.), and the technology-specific characteristics of the cooking device (e.g. human drudgery burden imposed by the cooking device, taste of food prepared with the device, durability of the cooking device, etc.) and a disturbance term having a zero mean:

$$U_{ki} = \alpha_k R_i(T_i, P_i) + e_{ki} \qquad k = 1,0; i = 1,\ldots,n \qquad (3.4)$$

Equation (3.4) does not restrict the function *R* to be linear. As the utilities U_{ki} are random, the i^{th} household will select the alternative $k = 1$ if $U_{1i} > U_{0i}$, or if the non-observable (latent) random variable $y^* = U_{1i} - U_{0i} > 0$. The utility-maximising household will adopt a new technology only if the random utility of the technology $U_{1i} > U_{0i}$. The probability that $Y_i = 1$, i.e. that the household adopts a BCS, is a function of the independent variables:

$$Pi = \Pr(Y_i = 1) = \Pr(U_{1i} > U_{0i})$$

$$= \Pr\left[\alpha_1 R_i(T_i, P_i) + e_{1i} > \alpha_0 R_i(T_i, P_i) + e_{0i}\right]$$

$$= \Pr\left[e_{1i} - e_{0i} > R_i(T_i, P_i)(\alpha_0 - \alpha_1)\right]$$

$$= \Pr(\mu_i > -R_i(T_i, P_i)\beta)$$

$$= R_i(X_i\beta) \quad (3.5)$$

where X is the $n \times k$ matrix of the explanatory variables, and β is a $k \times 1$ vector of parameters to be estimated, $\Pr(.)$ is a probability function, μ_i is a random error term, and $R(X_i\beta)$ is the cumulative distribution function for μ_i evaluated at $(X_i\beta)$. The probability that a household will adopt the BCS is a function of the vector of explanatory variables and of the unknown parameters and error term. As is common in the specification of utility functions, we assumed a cumulatively distinguishable utility function in the deterministic and stochastic components. Following equation (2), the functional form of R was specified with a Tobit model, where μ_i is an independently, normally distributed error term with zero mean and constant variance σ^2:

$$Y_i = (X_i\beta) \quad \text{if} \quad = y^* = X_i\beta + \mu_i > S$$

$$Y_i = 0 \quad \text{if} \quad = y^* = X_i\beta + \mu_i \leq S \quad (3.6)$$

where Y_i is the probability of adopting the BCS; y^* is a non-observable latent variable, and S is a non-observed threshold level. The underlying utility function, which ranks the preference of individual households for a given technology, is not observable. What is observed is a set of household attributes that influence a household's decision to adopt a given technology that yields the highest perceived utility. Thus, equation (3.6) is a simultaneous and stochastic decision model. If the non-observed latent variable y^* is greater than S, the observed qualitative variable y_i that indexes adoption becomes a continuous function of the explanatory variables, or is 0 otherwise. The model assumes that there is an underlying stochastic index equal to $X_i\beta + \mu_i$ which is observed when it is positive, and hence qualifies as an unobserved latent variable (Rahman, 2003).

Following a Tobit decomposition framework suggested by McDonald and Moffitt (1980), the effects of changes in given attributes and characteristics of households on adoption probabilities and use intensities can be obtained. We assumed $E(P_i)$ to be the expected value of the proportion of adoption across all observations conditional on the household being above the threshold limit. That is, we considered the use intensities of households that have already adopted the BCS. Given the probability of adoption as $F(z)$, where $z = XP/\sigma$, the relationship between these variables can be shown to be:

$$E(P) = F(z) * E(P) \tag{3.7}$$

The effect of household adoption behaviour can be disaggregated by differentiating equation (3.7) with respect to any change in the specific characteristics into: (1) a change in the elasticity of intensity of adoption of BCS (change in level of adoption) for households that have already adopted; and (2) a change in the elasticity of adoption (change in the probability of adopting) for households that have not adopted as follows:

$$\partial E(P)/\partial X_i = F(z)\left(\partial E(p)/X_i\right) + E(p)\left(\partial F(z)/\partial X_i\right) \tag{3.8}$$

Multiplying through by $X_i / E(P)$, equation (3.8) can be converted into elasticity form as:

$$\begin{aligned}&\left(\partial E(p)/\partial X_i\right)X_i / E(p) = F(z)\left(\partial E(p/)/\partial X_i\right)X_i / E(P) + \\ &E(p)\left(\partial F(z)/\partial X_i\right)X_i / E(P)\end{aligned} \tag{3.9}$$

Re-arranging equation (6) by using (4), the following decomposed elasticity equation can be obtained:

$$\left(\partial E(p)/\partial X_i\right)X_i / E(p) = \left(\partial E(p/)/\partial X_i\right)X_i / E(P) + \left(\partial F(z)/\partial X_i\right)Xi / F(z) \tag{3.10}$$

Therefore, total elasticity of a change in the level of any given characteristic (which is assumed to be directly linked to adoption) consists of two effects: (a) the change in the elasticity of the use intensities of the BCS for those households that are already adopters; and (b) the change in the elasticity of the probability of being an adopter.

A right censored Tobit model was used to analyse the influence of household perceptions in the adoption of BCS in Uganda. Among the limited dependent variable models widely used to analyse farmers' decision-making processes, Tobit analysis has gained importance since it uses all observations, both those that are at the limit, usually zero (i.e. non-adopters), and those above the limit (i.e. adopters), to estimate a regression line, as opposed to other techniques, which use observations that are only above the limit value (Rahman, 2003).

In this study, it was assumed that there could be some households that may not be using the BCS even after adoption. Therefore, they do not use biogas energy at all, hence the zero limit. In such cases, the application of Tobit model is most suitable because of the censored nature of the analysis. The other advantage is that the model not only measures the probability that a household will adopt the BCS, but also the intensity of use of the technology once adopted (Langyintuo and Mekuria, 2005). It is appropriate where technology adoption levels are presumed to be low (Adesina and Zinnah, 1993), as is the case with biogas energy in Uganda.

The empirical model was developed using both household socio-economic and demographic (household-specific) characteristics and user perception variables based on selected (technology-specific) characteristics of the BCS. The dependent variable was the proportion of total household energy use constituted by biogas energy for cooking purposes (measured from zero up to 100%). The independent variables were of two types: household-specific attributes (socio-economic and demographic characteristics of the household) and technology-specific attributes (household perceptions of selected characteristics of the cooking devices BCS and CCDs).

Household-specific variables were household size (SIZEHHLD), number of cattle owned by the household (LIVSTOCK), total monthly income of the household (INCOMHHLD), biogas production and use experience of the household head (BIOGEXPC) and gender of the household head (DSEHHLD). All of these were continuous variables except DSEHHLD, which was a dichotomous variable. Technology-specific variables, all measured as dichotomous variables, included perception of durability of cooking device (BIOGDUR); perception of taste of food prepared from cooking device (DIOGFTS); perception of initial cost of cooking device (DBIOGINC); perception of human drudgery burden imposed by cooking device (DBIOGHDR); perception of the need for spares and after-sales service by cooking device (DBIOGSPR); and perception of air pollution impact of using the cooking device (DBIOGAIR). A full list and definitions of all the variables included in the empirical model are given in Table 4.

The explanatory variables denoting household perceptions regarding technology-specific attributes are households' subjective assessments of the characteristics of the cooking devices (BCS and CCDs), the intention being to test the hypothesis that user perceptions significantly affect the adoption of BCS in Uganda. Of these, perception of the durability of cooking devices and perception of taste of food prepared from the cooking devices were expected to be positively related to adoption decisions of the household. The rest of the technology-specific variables were expected to negatively affect adoption decisions.

Table 4. Variables in the empirical model for effect of household perceptions on adoption of Biogas Coking Stove

Variables	***Variable definition and measurement***
Dependent	
BIOGPROPN,	Proportion of total energy use by household for cooking constituted by biogas
Independent	
LIVSTOCK	Number of cattle owned by household; a proxy for availability of the feedstock
SIZEHHLD	Household size denoted by the number of people in household
INCOMHLD	Total monthly income of the household in Uganda shillings (UGX); categorical variable: 1 = < UGX 500,000; 2 = UGX 500,000 - 1,000,000; 3 = >UGX 1,000,000[1]
BIOGEXPC	Household head's experience in biogas production and utilisation in years
DSEXHHLD	Gender of household head; 1= Male, 2= Female
BIOGDUR	Perception of durability of cooking devices used by household; 1 = If BCS was perceived to be superior to CCDs, 0 = Otherwise
DIOGFTS	Perception of taste of food prepared with cooking devices of the household; 1 = If food prepared with BCS was perceived to be superior to that prepared with CCDs, 0 = Otherwise
DBIOGINC	Perception of initial cost of BCS relative to cooking devices used by household; 1 = If the BCS was perceived to be superior to CCDs by involving a lower initial cost, 0 = Otherwise
DBIOGHDR	Perception of human drudgery burden imposed by cooking devices used by household; 1 = If BCS was perceived to be superior to CCDs by imposing a lesser burden, 0 = Otherwise
DBIOGSPR	Perception of the need for spares and after-sales service by cooking devices used by household; 1 = If BCS was perceived to be superior to CCDs by not requiring spares parts and after-sales services more regularly , 0 = Otherwise
DBIOGAIR	Perception of air pollution potential of cooking devices used by household; 1 = If BCS was perceived to be superior to CCDs by polluting the air less, 0 = Otherwise

[1]Exchange rate US$ 1 = UGX 1650

The few socio-economic and demographic attribute factors included in the model are based on the economic constraints and innovation diffusion theories. Among them, size of cattle herd owned by a household is a key factor in the biogas adoption process because cattle provide cow dung, the major feedstock for family-sized biodigesters in Uganda. It was used as a proxy for the availability of feedstock for the family-sized biodigesters and was expected to have a positive relationship with the probability of adoption of the BCS. Previous studies have shown that household size influences adoption decisions either positively or negatively (Kebede et al., 1990; Mendola, 2007). In this study, the size of household was expected to influence the adoption decision negatively because a larger family was expected to exert a heavier dependence burden on the family resources.

Uptake of technology is often influenced by household income. Households with higher income levels were expected to adopt the BCS more readily than their poorer counterparts. Household income was thus expected to carry a positive sign. Number of years of experience in biogas production and use was expected to be positively related to the ability of the household to obtain process and use information relevant to biogas production. Gender of household head was expected to have either a positive or negative effect. However, since women dominate rural energy use at household level (Karekezi, 2002), households headed by women could have a higher probability of adopting the BCS than those headed by males. This variable was therefore expected to carry a negative sign.

Three variations of the empirical model were estimated: (1) including only household socio-economic and demographic factors; (2) including only households' subjective perceptions of the technology-attribute factors; and (3) including both household socio-economic and demographic factors and perceptions of the technology-specific attributes.

3.4.3 Economic viability of biogas technology in Uganda

With incentives for biogas energy production and utilization in place, households would then need to evaluate whether it is worthwhile investing in biogas energy. This requires accessibility to vital information by households on the viability of biogas energy production and utilization for them to make rational decisions. Households will need to know whether biogas energy production from family-sized digesters is likely to increase or decrease costs relative to the associated benefits. The objective aims to assess the economic viability of biogas energy production from fixed dome biogas family-sized digesters, attempting to take into account all the costs and benefits accruing to the overall biogas energy production chain in Uganda. Based on this information and their resource endowments, households would need to assess how sustainable it is to produce and use biogas energy relative to alternative energy sources.

This objective is also intended to offer critical levels of operation within which the biogas systems can remain economically viable. For purposes of venture capital to invest in biogas energy production, it is imperative that households know the interest rates beyond which they should not borrow for their biogas systems and the discount rates and production levels within which the biogas energy systems can be profitable.

Standard analyses of economic viability of biogas energy production systems tend to emphasize primarily on direct financial costs and benefits associated with biogas production (Yiridoe et al., 2009). However, when considering the feasibility of biogas plants, non-economic factors must also be considered (CAEEDAC, 1999).

In this analysis, a comprehensive estimation of costs of the three most common biogas plant capacity designs (8, 12 and $16m^3$) was undertaken followed by the economic valuation of benefits of biogas energy from the digesters. The socio-economic parameters and technical parameters used in the study are shown in Tables 5 and 6, respectively. In evaluating the overall economic viability of biogas plants in Uganda this study adopted the framework developed by Kandpal et al. (1991) with modifications (Figure 7). This involved use of economic decision criteria commonly used to evaluate the viability of alternative investment opportunities. These include net present value, internal rate of return and payback period (Yiridoe et al., 2009).

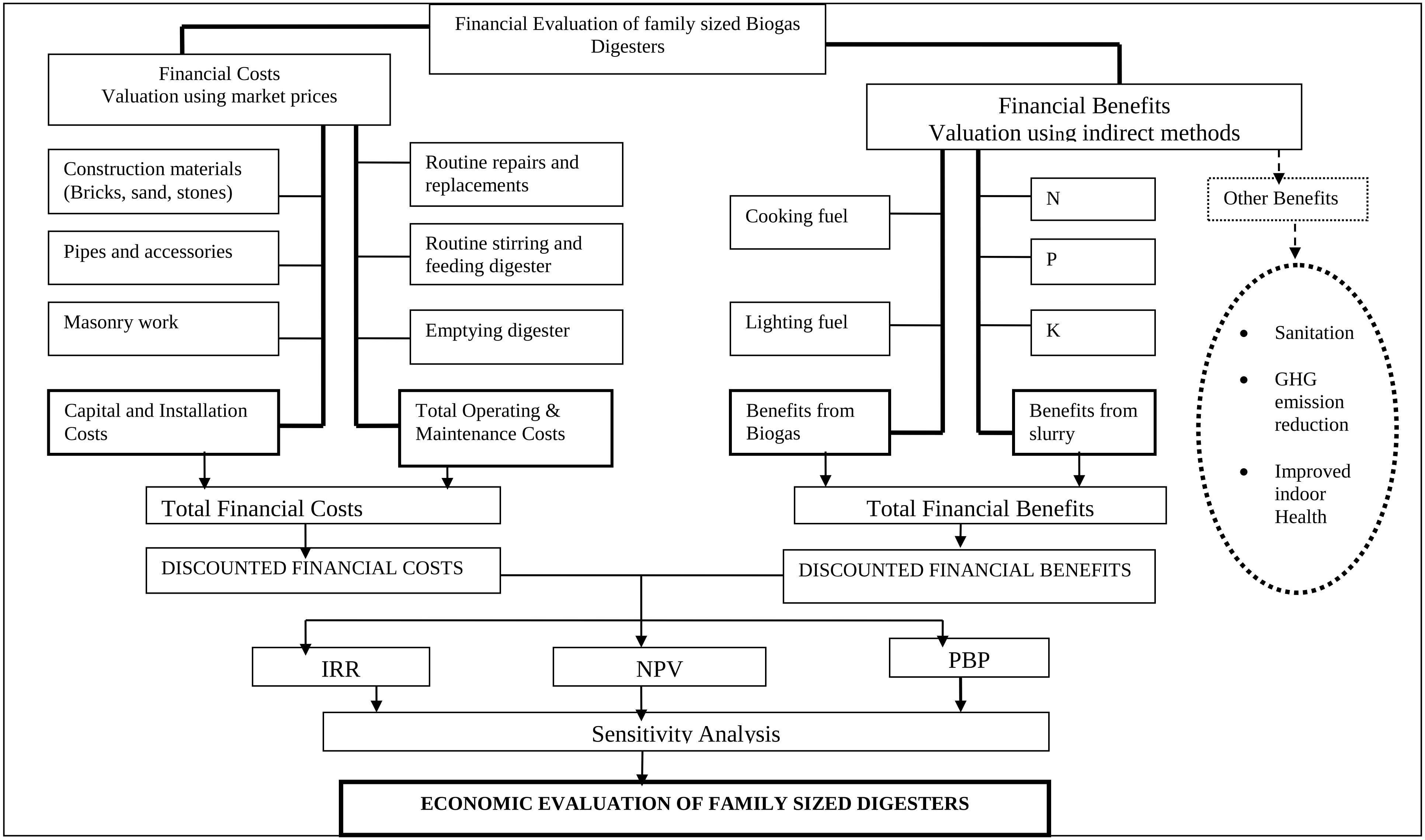


Figure 7. Framework for evaluating the economic viability of biogas energy production in Uganda (Kandapal et.al., 1991)

The use of economic decision criteria is important since the use of biogas-based systems often leads to both tangible and intangible benefits (Adeoti et al., 2000). While all the likely tangible benefits are normally taken into account in the financial evaluation exercises, the intangible benefits (such as additional benefits in terms of incremental fertilizer saving) are invariably not considered in the analysis (Purohit and Kandpal, 2007) rendering such evaluations questionable. All the three decision criteria were used because they consider different (but complementary) attributes of economic viability. Consistent results from the three decision criteria can help improve robustness of the analysis, as well as increase confidence in the viability of the investment opportunity. Other studies that used these criteria to assess the financial feasibility of on-farm biogas energy include Adeoti et al. (2000), Biswas and Lucas (1997), Caputo et al. (2005), Shinha and Kandpal (1990), Sullivan and Peters (1981) and Yiridoe et al. (2009). Finally sensitivity analysis through varying of parameter values on costs and revenues of the three biogas plant capacity designs ($8m^3$, $12m^3$ and $16m^3$) was undertaken.

3.4.3.1 Costs of the family-sized biogas plants in Uganda

Detailed data on inputs of the most adopted fixed-dome biogas plant design in Uganda were obtained and used to arrive at the various costs involved. The costs of establishing and running a biogas digester are dependent on the specific type and size of the digester (CAEEDAC, 1999). These include capital and installation costs and operating and maintenance (O&M) costs.

3.4.3.1.1 Capital and installation costs of family-sized plants in Uganda

Capital costs included the cost of civil construction of the digester plant (bricks, sand, cement, steel and iron bars, pipes, stone chips, labour for masonry work) and installation. The capital costs also include interest on financing of the plant (CAEEDAC, 1999). However, this was not included in this study because it was established from the survey that none of the respondents had acquired a loan for the purpose of constructing a biogas plant. To reduce capital costs, digesters in Uganda were built with local construction materials to local specifications. The economic prices of locally available materials (such as sand, stone chips and bricks) were valued at their market prices, while those of tradable components (such as cement, steel bars, etc.) were valued at retail market prices (Table 5).

Table 5: Socio-economic parameters used in the economic viability biogas energy production in Uganda

Parameter	*Symbol*	*Unit*	*Value*
Discount rate	i	Percent	12.00
Market price of bricks	-	UGX/brick	150.00
Market price of sand (lake)	-	UGX/ton	25000.00
Market price of sand (plaster)	-	UGX/ton	20000.00
Market price of stone chips	-	UGX/ton	80000.00
Market price of stones (hard core)	-	UGX/ton	80000.00
Market price of ordinary cement	-	UGX/kg	450.00
Market price of water-proof cement	-	UGX/kg	3000.00
Market price of lime	-	UGX/kg	300.00
Market price of PVC pipes (4”)	-	UGX/m	4000.00
Market price of chicken mesh	-	UGX/m^2	5000.00
Market price of weld mesh	-	UGX/m	3000.00
Market price of timber (2”x4”)	-	UGX/m	1500.00
Market price of nails	-	UGX/kg	5000.00
Market price of galvanised pipes (3/4” and ½”)	-	UGX/m	4500.00
Market price of gas valves	-	UGX/piece	10000.00
Market price of filter	-	UGX/piece	3000.00
Market price of biogas stove	-	UGX/piece	90000.00
Market price of biogas lamp	-	UGX/piece	110000.00
Market price of urea	pu	UGX/kg	1200.00
Market price of single super phosphate	pp	UGX/kg	1000.00
Market price of muriate of potash	pm	UGX/kg	1000.00
Market price of fresh cowdung	Pw_{du}	UGX/kg	50.00
Market price of kerosene	P_k	UGX/litre	1970.00
Market price of fuelwood	P_f	UGX/kg	50.00
Market price of unskilled labour in rural areas	WR_{ul}	UGX/man-day	2000.00
Market price of skilled masonry labour	WR_{sl}	UGX/man-day	10000.00

Table 6: Technical parameters used in the analysis of economic viability of biogas production in Uganda

Parameter	*Symbol*	*Unit*	*Value*
Total annual benefits from biogas plant	TAB_g	UGX	
Total annual benefits for use of biogas for cooking	TB_c	UGX	
Total annual benefits for use of biogas for lighting	TB_l	UGX	
Total capital and installation costs	TC_c	UGX	
Total annual cost of biogas plant	TAC_b	UGX	
Total annual operating and maintenance costs	AOT_c	UGX	
Amount of wet cowdung required to produce 1m^3 biogas	wd_u	kg	25.00
Calorific value of fuelwood	Q_f	kCal/kg	4708
Calorific value of kerosene	Q_k	kCal/litre	9122
Calorific value of biogas	Q_c	Cal/m^3	4713
Cooking efficiency of utilization of fuelwood stove	n_{ef}	fraction	0.12
Cooking efficiency of utilization of biogas stove	n_{eb}	fraction	0.60
Lighting efficiency of biogas lamp	n_{bl}	fraction	0.04
Lighting efficiency of kerosene lamp	n_{kl}	fraction	0.06
Useful lifetime of biogas plants	n	year	20.00
Rated biogas plant capacity	V	m^3/day	
Annual average gas production	a_p	fraction	0.80
Fraction of gas used for cooking	g_c	fraction	0.80
Fraction of gas used for lighting	$1-g_c$	fraction	0.20
N in fresh dung	N	fraction	0.02
P in fresh dung	P	fraction	0.063
K in fresh dung	K	fraction	0.025
Retention factor:	z_f	fraction	0.60

Kandpal et al. (1991) assert that the capital cost of any given plant design could be obtained using the following cost function:

$$C = C_0 \left[a + b \left(V / V_0 \right) \right] \qquad (3.11)$$

where C is capital and installation cost for a biogas plant of capacity V m^3, a and b are constants, values of which depend on the capacity, V_0, of the reference plant with the capital cost of C_0. Coefficients a and b are calculated by minimizing the least-square function for the cost of the biogas plants for different capacities. For this study, total capital costs, TC_c, were computed as costs of civil construction and installations. As a first approximation of capital costs, the annual economic value of the land occupied by the biogas system should be determined and included in the analysis. The land occupied by a biogas system has several alternative uses. A rough estimate of the cost of establishing an unheated biogas digester, not including the purchase or opportunity costs of land, was approximately 50-75 US dollars per m^3 capacity (CAEEDAC, 1999). However, a number of studies on economic evaluation of biogas systems in developing countries (Adeoti et al., 2000; Biswas and Lucas 1997; Caputo et al., 2005; Shinha and Kandpal, 1990; Yiridoe et al., 2009) have excluded the cost of land in their capital cost analysis because the biogas systems are often sited on the households' land. Increasing the cost of land would exaggerate the total cost of biogas plants and could discourage households from investing in this sector. This study has also excluded the cost of land in the analysis. The total capital and installation costs used in the study for the respective biogas plant designs are shown in Table 7.

Table 7: Estimation of capital and installation costs of family-sized biogas plants in Uganda

	Biogas plant capacity		
Name of component	*8m³*	*12m³*	*16m³*
A. Civil construction cost (UGX)			
Bricks	270,000	300,000	360,000
Sand -lake	100,000	100,000	100,000
Sand -plaster	80,000	120,000	200,000
Stone chips	120,000	160,000	200,000
Stones -hard core	80,000	80,000	80,000
Ordinary cement	360,000	450,000	562,500
Water-proof cement	15,000	18,000	21,000
Lime	30,000	45,000	52,500
PVC pipes (4”)	24,000	32,000	40,000
Chicken mesh	10,000	15,000	20,000
Weld mesh	12,000	18,000	28,000
Timber (2”x4”)	8,000	12,000	14,000
Nails	25,000	30,000	35,000
Subtotal	1,134,000	1,380,000	1,713,000
B. Labour cost (UGX)			
Digging the pit	500,000	800,000	1,000,000
For construction	300,000	500,000	700,000
Mason	500,000	800,000	1,000,000
Subtotal	1,300,000	2,100,000	2,700,000
C. Supply Line cost (UGX)			
Market price of galvanised pipes (3/4” and ½”)	22,500	22,500	22,500
Market price of gas valves	30,000	50,000	70,000
Market price of filter	3,000	3,000	3,000
Market price of biogas stove	90,000	90,000	90,000
Market price of biogas lamp	110,000	110,000	110,000
Subtotal	255,500	275,500	295,500
Total Cost (A+B+C)	**2,689,500**	**3,755,500**	**4,708,500**
Miscellaneous (5% of Total cost)	134,475	187,775	235,425
Grand Total	**2,823,975**	**3,943,275**	**4,943,925**

3.4.3.1.2 Operating and Maintenance Costs of family-sized plants in Uganda

The operating and maintenance *(O&M)* costs of the biogas system include the cost of various inputs to the biogas system as well as the cost of manpower required to operate the system (Purohit and Kandpal, 2007). Acquisition of raw materials for the substrate, water for mixing materials, feeding and operations of the plant, regular maintenance, supervision, storage and disposal of the slurry, gas distribution and utilisation, and administration are some of the O&M costs associated with running a biogas plant (CAEEDAC, 1999). Total O&M costs often include the sum of operating labour costs, feedstock costs, feedstock transportation costs and maintenance costs (Caputo et al., 2005).

In Uganda, the tasks of collection, stirring and feeding the substrate into the family-sized digester, were largely performed by household members to whom the biogas plant belonged. The average household size in the study area was 7.6, a size deemed to provide adequate labour to perform the required tasks for biogas generation. Most of the family-sized digesters are located within the homestead near the cattle sty. This makes the task of collecting the dung for biogas production by the household very easy. Thus, the cost of family labour for this purpose has been omitted in the present analysis because not so much labour is required in biogas energy production. Furthermore, the opportunity cost of unskilled labour is assumed to be zero in many developing countries due to considerably high unemployment levels (Purohit and Kandpal, 2007). It may, however, be noted that for larger biogas plants such as community and industrial biogas units and places with higher opportunity cost such an assumption may not hold. In such cases, the labour cost would have to be incorporated into the evaluation. The amount of water used in the biogas system (essentially for preparation of input slurry) is a small fraction of the water delivered by the system, estimated at less than 1% of O&M costs (Purohit et al, 2007). Therefore, in the present work the cost of water has not been taken into account.

The cost of fresh dung input for the family-sized biogas plants, especially where cowdung is purchased, is considered the main operational cost. Where it is not purchased, its economic cost could be estimated on the basis of monetary worth of (a) equivalent amount of fertilizer saved, (b) equivalent amount of fuels purchased (such as fuelwood, kerosene, etc.), and (c) gathered fuelwood (Purohit and Kandpal, 2007; Singh and Sooch, 2004; Sinha and Kandpal, 1990). However, since the dung was assumed to be readily available to the households in the study areas, an average price derived from the survey results as the maximum price the household was willing to pay for the cowdung has been used to estimate the cost of fresh dung.

The other annual O&M costs of the biogas plants were repair, maintenance and replacement costs. The repair and maintenance requirement of the digesters usually consisted of mainly the cost of maintenance and replacement of gas valves, lamp and cooking stove parts and fixing gas leakage points. Emptying the digesters of accumulated solid particles after every five years was also required for the plant to achieve the maximum lifespan. For the analysis presented here, following Kandpal et al. (1991), a figure of 4% of the capital cost is assumed to be adequate for the maintenance cost because the approximate cost of these and other routine maintenance costs have been shown to be roughly proportional to the capital costs of the plant capacity. Similar studies (Khandelwal and Mahdi, 1986; Sinha and Kandpal, 1990) note that the annual maintenance cost is always about 4% of the capital cost of the plant. Thus, once the capital is known, the total annual maintenance cost, M_c, for a biogas plant of capacity V m^3 can be estimated as:

$$M_c = 0.04C \tag{3.12}$$

Where M_c is the annual maintenance cost for a biogas plant of capacity Vm^3 and C is its total capital and installation costs. The total annual operating and maintenance costs, AOT_c, for a plant of capacity V m^3 with capital cost C, could thus be:

$$AOT_c = 365VWP_{wdu} + 0.04C \tag{3.13}$$

where W is quantity (kg) of wet dung required to produce 1m^3 of gas, P_{wdu} is the price of the dung in UGX/ kg, and 365 refers to 365 days in a year. For end-use equipment, materials and fuels (such as biogas stove, chemical fertilizers, diesel, kerosene etc.) the 2008 retail market prices were used in the calculations (Table 5). The costs of depreciation and maintenance were calculated as fixed percentages of the capital costs (Kandpal, 1991). The total annual cost, TAC_b, of the family-sized biogas plant included the total capital and installation costs, TC_c, and the total annual operating costs, AOT_c.

3.4.3.2. Benefits of family-sized biogas plants

Quantification of the benefits of a biogas system is a crucial step in the economic viability evaluation of biogas generation. The benefits accruing from establishing and running a biogas digester fall into two basic categories: monetary and environmental (CAEEDAC, 1999) as shown in Figure 8. The monetary benefits are the saved costs on fuels substituted by biogas, and on fertilizer costs substituted by digester slurry (Bishwas and Lucas, 1997; Purohit and Kandpal, 2007). Environmental benefits include several other indirect benefits.

The most notable is the mitigation of methane, a greenhouse gas (GHG) released from open decomposition of animal wastes and the avoided carbon dioxide release from burning firewood (Srinivasan, 2008). Furthermore, reduced use of firewood as a result of biogas use checks deforestation. By encouraging increased zero grazing by farmers to capture manure conveniently, family-sized digesters reduce overgrazing and greatly improve sanitary conditions of the household.

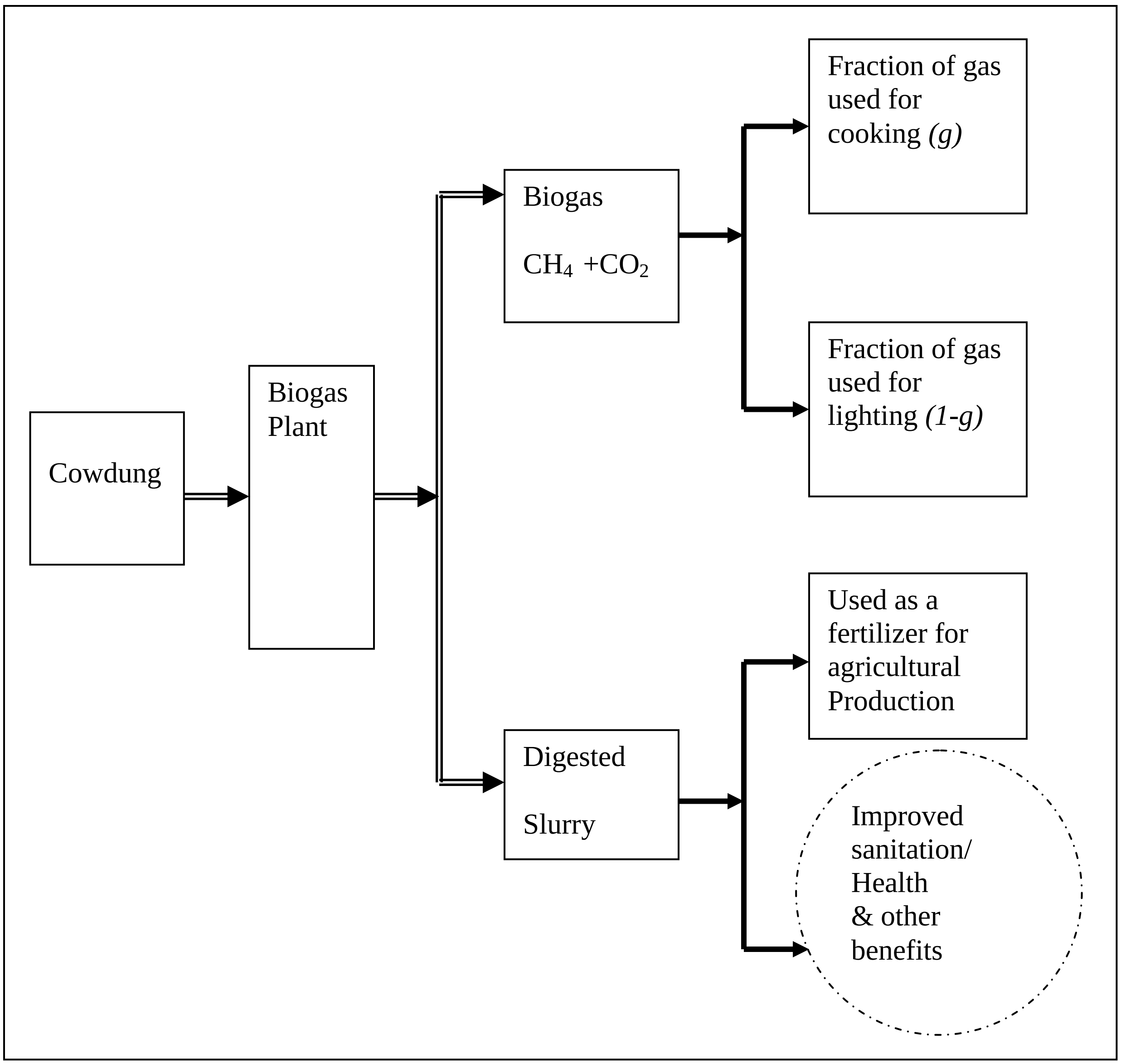


Figure 8. Benefits from family- sized biogas systems (Survey data, 2007)

However, attributing market prices to the major benefits of biogas plants; the biogas and the digested manure (slurry) and other indirect benefits, is rather difficult (Daxiong et al., 1990; Kandpal et al., 1991; Sinha and Kandpal, 1990). Some households do not appreciate the monetary value of biogas production because they have adequate supplies of biomass at almost no cost and they attach little or no value on time spent gathering the biomass (Bishwas and Lucas, 1997; Sinha and Kandpal, 1990). Under-employment and unemployment also lead to a zero or negligible opportunity cost for collecting various biomass for domestic energy requirements (Purohit and Kandpal, 2007). Hence it is necessary to find an indirect method to evaluate the benefits, and the most logical method is to place market values in terms of alternative fuels for a given end use (Kandpal et al., 1991; Rubab and Kandpal 1996; Singh and Sooch, 2004).

3.4.3.2.1 Valuation of biogas from family-sized biogas plants for energy use

Biogas in Uganda is mainly used for cooking and lighting purposes (Walekhwa et al., 2009). The benefits for the users of biogas systems in this study were therefore quantified in terms of the quantity of fuelwood the biogas replaces for cooking and the quantity of kerosene substituted for lighting. In Uganda, fuelwood meets about 80% of the energy needs for cooking, while kerosene is the major source of lighting for more than 90% of the households in rural areas where biogas has been largely promoted (MFPED, 2002). This makes it the most logical benchmark for comparison and evaluating the monetary benefits of family-sized biogas digesters in Uganda. The value of benefits from cowdung for generating biogas for cooking and lighting often depends upon the previous end-uses of the cowdung before being substituted for biogas production (Rubab and Kandpal, 1996).

In this study, it has been assumed that the dung was previously used directly as farm yard manure only, but with the advent of biogas generation, all the dung was reserved for the generation of biogas energy.

Following Kandpal et al. (1991), for a biogas plant of capacity V m^3, the total annual monetary worth of benefits from cooking, TB_c, was computed as:

$$TB_c = 365Va_p g_c \frac{Q_c n_{eb}}{Q_f n_{ef}} p_f \qquad (3.14)$$

where a_p, represents the annual average daily biogas production as a fraction of its rated capacity, g_c is the fraction of gas used for cooking, Q_c is the caloric value of biogas (in kJ/m^3), n_{eb} is the efficiency of a biogas cooking stove, Q_f is the caloric value of fuelwood (in kJ/kg), n_{ef} is the efficiency of fuelwood cooking stove, and p_f is the price of the fuelwood (in UGX/kg).

The annual worth in terms of monetary benefits from the use of biogas for lighting, B_l, (UGX) was similarly computed as:

$$TB_l = 365Va_p (1 - g_c) \frac{Q_c n_{bl}}{Q_k n_{kl}} p_k \qquad (3.15)$$

where Q_k is the caloric value of kerosene (in kJ/litre), n_{bl} *and* n_{kl} are the efficiencies of biogas and kerosene lamp for lighting, respectively, (1-g_c) is the fraction of gas used for lighting and p_k is the price of kerosene (in UGX/litre). Thus, the total annual benefits, TB_g, from the use of biogas for lighting and cooking (in UGX) are the sum of equations (3.04 and 3.05) as follows:

$$TB_g = 365Va_p\left[g_c \frac{Q_c n_{eb}}{Q_f n_{ef}} p_f + (1 - g_c) \frac{Q_c n_{bl}}{Q_k n_{kl}} p_k \right] \quad (3.16)$$

3.4.3.2.2 Valuation of slurry as fertilizer from family-sized biogas plants

The cow dung used to run a biogas plant is a double-pronged source of income to the household. Firstly, the biogas is a fuel of appreciable calorific value. Secondly, the residual slurry is a good manure of appreciable nutritional value (Singh and Sooch, 2004). Biogas plants thus provide fertiliser in the form of spent slurry and can be compared with aerobic composting processes or the provision of chemical fertilizers (Kandpal et al., 1991; Sinha and Kandpal, 1990).

It has been documented that if post-digestion handling of slurry is appropriate, it may be assumed that there is no significant change in the fertilizer value of cowdung manure after undergoing anaerobic digestion (Bishwas and Lucas, 1997; Sinha and Kandpal, 1990). Hence slurry contains reasonable quantities of the nutrients (sodium, potassium and phosphate) found in chemical fertilizers like urea, potash and superphosphates (Bishwas and Lucas, 1997). Therefore slurry removed after optimal retention time in the anaerobic digester has value as fertilizer and soil amendment, not only because it retains most of the macronutrients (N, P and K) in the original feedstock, but also because such nutrients are readily available as crop nutrients (Yiridoe et al., 2009). Similarly, if composting is appropriate, farmyard manure (FYM) will have almost the same NPK value as the fresh manure (Rubab and Kandpal, 1996) and the quantity of residual slurry is the same as that of the cow dung fed in a biogas plant (Sinha and Kandpal, 1990).

Some studies have reported that the digester effluent has more available nutrients than raw manure and it is more environmentally friendly and less costly than chemical fertilizers (CAEEDAC, 1999). It has also been reported that nitrogen present in cattle dung is conserved when processed through a biogas plant, yet in open-pit composting, some of the nitrogen may be lost due to evaporation (Kandpal et al., 1991). However, the nitrogen in ammoniacal form, which is present in the digested slurry, may also be lost when the slurry is spread or sun-dried (Sinha and Kandpal, 1990). In view of the differing claims by researchers, it is difficult to conclusively state how much of the quantifiable incremental benefit of using spent slurry from anaerobic processes over FYM can be obtained through aerobic composting. But the general agreement in the various views is that slurry has significant value as fertilizer for boosting agricultural production.

This study used market prices of urea, superphosphate and muriate of potash, respectively (Table 1), to attempt to quantify the benefits for the N, P and K values in the digested slurry from a biogas plant as was done by some studies (Purohit and Kandpal, 2007; Rubab and Kandpal, 1996; Singh and Sooch, 2004; Sinha and Kandpal, 1990). Hence cognisant of the varying views about the quality of the digested slurry as a fertilizer, it was assumed that a certain percentage of nitrogen remains after the animal dung is digested anaerobically in a biogas plant, and that this percentage is defined by the nitrogen retention factor, z_f. It is also worth mentioning that the quantity of residual slurry is said to be the same as that of the cowdung fed into a biogas plant (Singh and Sooch, 2004). If the quantity of wet dung required to produce $1m^3$ of biogas is wd_u kg, the nitrogen present in fresh dung (by weight fraction) is N and the price of urea is p_u (UGX/kg). The annual worth of the monetary benefits (in terms of urea equivalent) from the digested slurry, S_b, was thus expressed as:

$$S_b = 365Vwd_u Nz_f (100/46) p_u \qquad (3.17)$$

where nitrogen content in urea was taken at 46%. The NPK values of urea, superphosphate and muriate of potash were taken as 46, 16 and 40, respectively. The annual incremental benefits of the P and K values of the spent slurry were expressed, respectively, as follows:

$$S_b = 365Vwd_u Pz_f (100/16) p_p \qquad (3.18)$$

$$S_b = 365Vwd_u Kz_f (100/40) p_m \qquad (3.19)$$

The total annual incremental benefit from the spent slurry then became:

$$S_b = 365Vwd_u \left[Nz_f (100/46) p_u + Pz_f (100/16) p_p + Kz_f (100/40) p_m \right] \qquad (3.20)$$

Thus the total annual benefits, TAB_g, due to the installation of a biogas plant of Vm^3 were computed as the sum of the benefits arising from the use of biogas as well as those from the digested slurry used as fertilizer; the sum of equations (3.16) and (3.20):

$$TAB_g = 365Va_p \left[(1 - g_c) \frac{Q_c n_{bl}}{Q_k n_{kl}} p_k + g_c \frac{Q_c n_{eb}}{Q_f n_{ef}} p_f + 2.17wd_u Nz_f p_u + 6.25wd_u Pz_f p_p + 2.5wd_u Kz_f p_m \right] \qquad (3.21)$$

Biogas energy generation has indirect benefits. For the present analysis, the monetary values of these indirect benefits have not been included due to lack of sufficient data. These benefits include (i) partial sterilization of waste during fermentation, with the consequent reduction of public health hazard, (ii) improvement in sanitation, (iii) reduced transfer of fungus and other plant pathogens from year's crop residue to the next year's crop, (iv) provision of better fuel than natural gas and liquefied petroleum gas because it does not contain sulphur, thereby reducing sulphur dioxide emission, (v) reduced deforestation as a result of reduced use of fuelwood and (vi) reduced overgrazing through increased use of zero grazing by farmers to capture manure conveniently.

3.4.3.3 Economic viability of biogas energy production from family-sized biogas plants

After quantification and valuation of the costs and benefits of the biogas systems, three economic decision criteria were used in the analysis of the economic viability, namely, payback period (PBP), net present value (NPV) and internal rate of return (IRR).

3.4.3.3.1 Payback period

Payback period (PBP) refers to the number of years it would take for an investment to return its original cost of investment through the annual net cash revenues it generates. If the net cash revenues are constant each year, the PBP can be calculated as:

$$PBP = TI / NR \qquad (3.22)$$

where,

TI = Amount of total Investment; NR = Annual net revenue (net profit) which is annual gross income less annual operational cost. Where the net cash revenues are not equal, they should be summed year by year to find the year where the total is equal to the amount of investment. Investments with a shorter PBP are preferred. In this study, annual net revenues were assumed to be equal and the undiscounted Payback period (UPBP) was used in the analysis because of its suitability for computations where annual benefits and annual operating costs are assumed uniform over lifetime of the project. It is calculated as:

$$UPBP = \frac{CI}{AP} \tag{3.23}$$

where: CI = Total Capital and installation costs, AP = Annual profit which is annual income less annual operational cost (Singh and Sooch, 2004).

3.4.3.3.2 Net present value

Net present value (NPV) is a way of comparing the value of money now with the value of money in the future. It refers to the sum of the present values for each year's net cash flow less the initial cost of investment. It is used to determine whether the total current value of a project's expected future cash flows is enough to satisfy the initial cost. The future sum of money is discounted back to the present to find the present value of that expected future sum.

A useful economic life of a fixed-dome digester of 20 years was assumed in this study as has been in other similar studies (Adoeti et al. 2000; Bishwas and Lucas, 1997; Rubab and Kandpal 1996; Sinha and Kandpal, 1990). Investments with a positive NPV are preferable. This implies that the rate of return by the investment is higher than the discount rate used and is greater than the opportunity cost of capital used as the discount rate. A negative NPV should be rejected while a zero NPV makes the investor indifferent, in which case other factors and benefits relating to the investments should be considered. Assuming that the annual benefits, TAB_b, and annual operating costs, AOT_c, are uniform over lifetime, t, of the biogas plant, the expressions for TAB_b and AOT_c, given by equations (3.11) and (3.03) respectively, were used to calculate the NPV of the benefits from the expression:

$$NPV = TAB_b - AT_c$$

$$NPV = \frac{(TAB_b - AOT_c)\left[1-(1+i)^{-t}\right]}{i} - C \qquad (3.24)$$

where C is given by equation (3.01), i is the interest rate, and t is the expected lifetime of the fixed-dome biogas plant; t = (1, 2 … 20).

3.4.3.3.3 Internal rate of return

Internal rate of return (IRR) is a financial analysis tool that estimates the interest rate which would make the present value of a stream of net cash revenues equal to zero. An alternative explanation might be: the highest rate of interest (expressed as a percentage) at which an investment can be funded if cash flow generated is to be sufficient to repay the original outlay at the end of the project life. It was calculated as:

$$\sum_{t=0}^{n}(TAB_b - C)_t(1+irr)^{-t} = 0 \qquad (3.25)$$

where irr is the discount rate. IRR higher than the discount rate means the investment is profitable.

3.4.3.3.4 Sensitivity analysis of selected economic parameters

Sensitivity analysis using estimated economic values (costs and benefits) from the family-sized biogas digesters was undertaken. There are many assumptions and uncertainties involved in the cost benefit analysis. The parameters may vary due to location (such as the price of fuel wood, interest rates), technology development (such as the change of lifetime biogas plants, improvement of cooking stove efficiency) and other factors (Kandpal et al., 1991). Sensitivity analysis is used to incorporate uncertainty into economic evaluation in order to generalize the results for different situations where input parameters and costs differ (Odeh et al., 2006). It explores the net effect on the net present cost of the systematic changes in individual parameters (Wilson, 1979). Sensitivity analysis was thus performed by varying the discount rate, capital costs, and operating and maintenance costs to determine the economic stability of family-sized biogas energy production.

In this study, sensitivity analysis was performed at three different discount rates scenarios; 6% (50% reduction in the base case scenario discount rate), 12% (base case scenario) and 24% (doubling the base case scenario discount rate). Generally, the discount rate of 12% is conventionally used to annualise capital investments (Gupta and Ravindranath, 1997). The 12% discount rate is thus regarded as the standard rate for valuation of most economic projects. It was thus chosen as the base case scenario for this study.

Although the 12% discount rate is often regarded as standard, the actual interest rates paid by the borrower may be much higher. In Uganda, some financial institutions, such as commercial banks, lend at interest rates as high as 24%, and even higher for some informal financial institutions like private money lenders. For instance, the average commercial bank interest rate in Uganda was about 24% for short-term consumer loans at the time of this study. Hence the most logical basis for doubling the base case discount rate to 24% to cater for the effect of high discount rates on the economic stability of the biogas energy production. Sometimes market situation changes in demand and supply for money can lead to a reduction in the interest rates charged. In Uganda, for instance, because of increased competition among commercial banks as a result of entry of many banks into the industry, a number of them have started decreasing their lending interest rates. This study hypothesizes that this trend could continue. However, the 50% reduction in the discount rate should be the feasible lower limit. This thus formed the basis for the selection of 6% (a 50% reduction) as the minimum discount rate.

Market situation changes in demand and supply of inputs required for biogas energy production can lead to either a reduction or increase in capital and operating and maintenance (O&M) costs. For instance, because of inflation, capital costs can double or even treble depending on the inflationary rate. Alternatively, in case of cost sharing or a government subsidy, capital costs incurred by a household can significantly drop. Also where households collect or buy the dung, O&M costs can be reduced if the household starts rearing cattle where the plant is sited. Alternatively, O&M costs can hike if the household starts hiring labour for biogas energy production.

In this study, it is envisaged that such increases or reductions in capital and O&M costs may not exceed 50% based on the recent past, current and/or foreseeable future trends in biogas input and commodity markets in Uganda. Hence the basis for a 50% increase and decrease in capital and O&M costs for the sensitivity analysis. Other more specific reasons for the justification of 50% increase or decrease in the costs are indicated in Table 8.

Table 8: Sensitivity analysis parameters and scenarios for analysis of economic viability of biogas energy production in Uganda

Parameter	*Scenario*	*Variation*	*Reason*
	ONE	Base-case	No Variations in cost or parameter values from the base case inputs
Discount rate	TWO	Doubled to 24%	• Market situation changes in demand and supply for money. • Increase in inflation rate
		Reduced by 50% to 6%	• Market situation changes in demand and supply for money. • Decrease in inflation rate
Capital cost	THREE	Increased by 50%	• Higher component prices • Increased depreciation rates
		Decreased by 50%	• Lower component prices • Longer lifetime of the biogas plant
O&M Costs	FOUR	Increased by 50%	• High cowdung cost • Higher labour wages • Higher maintenance costs • Shorter component lifetime
		Decreased by 50%	• Lower cowdung cost • Lower labour wages • Lower maintenance costs • Longer component lifetime

Sensitivity analysis was also performed to determine the break-even points for the respective capacity plants. To ensure sustainable economic viability of biogas energy production, it is imperative that households avoid making losses. This can be achieved through monitoring the profitability of their biogas production systems. Break-even analysis is a crucial tool in empowering households to achieve this objective. The break-even point is where the NPV for the biogas plants equal to zero. This implies that the discounted stream of costs equal to discounted benefits, i.e., the profitability of the biogas system is equal to zero. Any increase in the cost streams beyond the benefits leads to negative NPV; the biogas production system starts incurring losses. By use of the NPV economic decision criteria, break-even points for the respective biogas plants were determined through sensitivity analysis by varying total cost and O&M costs at 12% and 24% discount rates. The 12% discount rate was chosen because it is the rate conventionally used to annualise capital investments while 24% was the interest rate charged by commercial banks for short-term loans at the time of this study. The data used in the sensitivity analysis are shown in Table 9 below.

Table 9: Data for Sensitivity Analysis and effect of variations in economic parameters

	Biogas Plant capacity		
Name of component	*8m^3*	*12m^3*	*16m^3*
(Million UGX)			
Total Cost	6.70	9.73	12.64
Capital Costs	2.82	3.94	4.94
Total (O&M) Costs	3.88	5.79	7.70
Total Annual Income	6.29	9.44	12.58
50% increase in Capital costs:			
Total Cost increases	8.11	11.71	15.11
50% decrease in Capital costs:			
Total Cost decreases	5.29	7.76	10.17
50% increase in O&M costs:			
Total cost increases	8.64	12.63	16.49
Total O&M increases	5.81	8.69	11.54
50% decrease in O&M costs:			
Total cost decreases	4.76	6.84	8.79
Total O&M decreases	1.94	2.90	3.85

3.4.4 Estimates of Potential biogas energy from animal wastes

Households also need to be assured of reliable and cheap sources of raw materials (substrates) for production of biogas energy. There are many potential sources of substrates for biogas energy production; including crop wastes, animal wastes, household wastes, industrial and water wastes and human wastes. However, based on the available conversion technologies, only cowdung is currently the major feedstock for the production of biogas energy in Uganda. Yet, statistics on the quantity of biogas energy produced from animal wastes; the only feasible substrate source at the moment and in the near future, are not readily available. This statistical invisibility of how much biogas energy is currently produced and/or could be potentially generated in Uganda greatly affects proper planning and potential investment in this important energy sector. The fourth objective of this study estimates the potential biogas energy that can be generated from animal wastes; the major source of substrate for biogas energy from family-sized digesters in Uganda.

To achieve this objective, the study relied on secondary data. By use of statistics from the National Population and Housing Census of 2002, livestock populations in the country for the period 2010 were estimated. Based on these livestock population projections (Table 10), the potential biogas energy that can be generated from animal wastes was assessed using the methodology of the Organization for Economic Cooperation and Development (OECD). This methodology uses the coefficient of conversion for the respective animals (Table 11) to arrive at the total energy potential and recoverable energy from the animal wastes (Tasdemiroglu, 1988).

Table 10. Livestock population estimates for Uganda from 2002-2010 ('000)

Livestock type	Annual growth rate (%) 1990-2000	Livestock population estimates								
		2002	2003	2004	2005	2006	2007	2008	2009	2010
Cattle	2.0	6,075	6,197	6,320	6,447	6,576	6,707	6,841	6,978	7,118
Sheep & Goats	3.1	7,993	8,241	8,496	8,760	9,031	9,311	9,600	9,898	1,0204
Pigs	3.1	1,710	1,763	1,818	1,874	1,932	1,992	2,054	2,118	2,183
Poultry	2.3	4,505	4,609	4,715	4,823	4,934	5,048	5,164	5,282	5,404

Table 11. Total and Recoverable Biogas energy potential from Animal wastes

Livestock Type	**Total number of animals (thousand head)[a]**	**Coefficient[b] of conversion (ktoe per thousand of animals)**	**Total energy potential(ktoe)**	**Recoverable[c] energy potential(ktoe)**
(1)	(2)	(3)	(4) = (2) X (3)	(5) = (4) X (0.3)
Buffalo cow, Buffalo oxen, Male buffalo, Horse,Camel		0.245		
Cow, Oxen, Bull Mule, Donkey		0.167		
Young cattle, Young buffalos		0.093		
Sheep and Goats		0.048		
Pig		0.022		
Poultry		0.0024		

a= Total number of animals from national statistics
b= Organization for Economic Cooperation and Development (OECD), 1984
c=Percentage of recoverable energy taken at 30% for all kinds of animals
Source: Tasdemiroglu, 1988.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This section presents the results of the study and their discussion based on the objectives of the study.

4.1 Factors influencing biogas production and utilization in Uganda

4.1.1 Profiles of biogas users and non-users in Uganda

The mean and percentage values of the variables predicted to influence a household's decision to adopt biogas energy were computed and are shown in Table 12.

Table 12. Descriptive statistics of selected variables for the biogas energy adoption model in Uganda

Variable	*Biogas users* (N=84)	*Non-users* (N=136)	*Total sample* (N=220)
AGEHHD	53.310	46.309	48.981*[1]
EDUCHHD	12.881	10.390	11.341*
SIZEHHD	7.619	9.485	8.773*
LANDSIZE	8.955	8.709	8.803*
LVSTOCK	3.452	6.691	5.455*
FWDCOST	703.869	1148.529	978.750*
KERCOST	9142.857	2746.324	5188.636*
SEXHHD *(%)*			
Male	69	77.2	74.1
Female	31	22.8	25.9
LOCHHD *(%)*			
Rural	56	66.9	62.7
Urban	44	33.1	37.3
INCOMHHD *(%)*			
< USh500,000	82.1	83.8	83.2
USh500,000- 1,000,000	16.7	14.7	15.5
>USh1000,000	1.2	1.5	1.4

[1]* Indicates that the difference between biogas users and biogas non-users is statistically significant at $P<0.05$ (t-test used for the difference in means)

The analyses show that out of a sample of 220 biogas user and non-user households, 74.1% were headed by men, 62.7% were located in rural areas and 83.2% earned a monthly income of less than USh 500,000. Gender composition, geographical location and monthly household income earning patterns were similar between biogas users and non-users. Only 1.2% and 1.5% of the biogas users and non-users, respectively, had a monthly income of more than USh 1,000,000 (Table 12). On average, biogas users were older, had more years of formal education, owned a larger area of land and spent more on kerosene for household lighting purposes than their counterparts. However, the biogas non-users had larger households, reared more livestock and incurred more expenses for fuelwood for cooking purposes.

Family-sized biogas plants being labour intensive and operated by mainly family members, implies that most households had sufficient manpower for the generation of biogas. The average cattle herd size of four suggests that most households had sufficient quantities of cowdung to generate adequate gas for both cooking and lighting. Households were considered to have biogas plant potential if they had at least two cows per capita (Adeoti et al., 2000). Results therefore show that there was adequate feedstock and manpower potential for sustainable biogas energy generation in the studied areas. Insufficient dung (cattle number) and/ or competitive uses for dung have often resulted in households abandoning the technology because of their inability of the biogas plants to generate adequate cooking energy (Bhat et al., 2001).

The cowdung-human ratio is noted to be a good measure of dung resource availability which is the major raw material for biogas generation. Thirty percent of the households reported that all their normal daily cooking energy needs were met through biogas. The average number of cooking per household per day was three times.

4.1.2 Factors influencing biogas energy production and utilization in Uganda

Comparisons between adoption studies need to be made cautiously, using a rigorous conceptual framework and sufficient data, if reliable interpretation is to be achieved. Differing objectives and methods lead to differing issues being examined and reported and the actors affecting adoption change over the technology diffusion cycle (Floyd et al., 2003). For the logistic model (Table 13), the estimated values fitted the observed data reasonably well. Measures of goodness-of-fit of the model results indicated that the independent variables were simultaneously related to the log odds of adoption. The choice of independent variables correctly predicted households' biogas adoption conditions for 90.4% of the total observations. The Cox and Snell R^2, an analogous measure of goodness-of-fit, was 50%, while the Nagelkerke R^2 was 69%. This is more than adequate for cross-sectional data. The Hosmer and Lemeshow test χ^2 test of goodness-of-fit, the recommended test for overall fit of a logistic regression model considered more robust than the traditional chi-square test, particularly if continuous covariates are in the model or sample size is small (Garson, 2008), was non-significant (Table 13). This indicates that the model fitted the data to an acceptable level.

Table 13. Binomial logistic regression estimates of biogas energy adoption model in Uganda

Variable	*Coefficient*[1]	*Standard error*	*Wald*	*Odds ratio*
Constant	3.017**	1.358	4.934	20.433
AGEHHD	-0.082***	0.021	15.171	0.922
EDUCHHD	-0.084*	0.48	3.080	0.919
SIZEHHD	0.200**	0.072	7.766	1.222
LANDSIZE	-0.017	0.025	0.448	0.983
LVSTOCK	0.184**	0.090	4.196	1.202
FWDCOST	0.002***	0.000	20.472	1.002
KERCOST	0.000***	0.000	31.214	1.000
SEXHHD	0.360	0.480	0.561	1.433
LOCHHD	-0.676	0.463	2.133	0.508
INCOMHHD	0.664	0.566	1.298	1.905

[1]*** *(* *)* * denotes significant difference at P<0.01, 0.05 and 0.1, respectively

-2 Log likelihood value = 138.316

Hosmer and Lemeshow test χ^2 = 3.110 (p>0.05)

Cox and Snell R^2 = 0.504

Nagelkerke R^2 = 0.685

% of correct prediction for biogas users = 90.4 (123 households out of 136)

% of correct prediction for non-biogas users = 77.4 (65 households out of 84)

% of total correct prediction = 85.5 (188 households out of 220)

Among the ten variables included in the model, the Wald χ^2 test results for six of these indicated that they had a statistically significant influence on adoption of biogas (Table 13). These included age of household head, formal education of household head, household size, number of cattle owned by the household and the costs of fuelwood and kerosene. The area of land owned by the household, gender of household head, location of the household and income of household were statistically non-significant.

As predicted, increasing household income, number of cattle owned by household, fuelwood cost and kerosene cost were found to have a positive correlation with adoption of biogas energy. Except for household income, the other three variables were statistically significant at $P<0.05$, $P<0.01$ and $P<0.01$ respectively. Increasing age of household head and household size and location of the household were found to be negatively correlated with adoption of biogas energy, with age of household head and household size statistically significant at $P<0.01$ and $P<0.05$ level respectively. Contrary to the hypothesis, formal education level of the household head, though statistically significant at $P<0.10$, was negatively correlated with biogas adoption.

The results from the model reveal that characteristics of households could be a good source of knowledge on the reasons why households may or may not adopt this technology. Many programmes aimed at promoting a given technology have tended to focus more on the technical aspects of the technology disseminated. However, the results of this study show that socio-economic characteristics of the target beneficiaries are crucial in the popularisation of biogas technology. A number of studies on adoption of biogas energy suggest that barriers to the popularisation of biogas technology include technical, economic and socio-cultural constraints. The development and management of biogas technology are far from a purely technical question and almost always involve economic and social problems and human behaviour characteristics (Mendola, 2007).

In this study, age of household head was found to have a significant ($P<0.01$) negative relationship with biogas technology adoption, i.e. the probability of younger household heads adopting biogas technology was higher than that of their older counterparts. This result is similar to findings by Somda et al. (2002) where farmer age was negatively related to the probability of adopting compost technology. This confirms that older people are more risk-averse and less willing to take on new innovations.

Contrary to our hypothesis, logistic results revealed that the education variable was negatively related with the log odds of biogas energy adoption, such that the likelihood of adoption of biogas energy decreased with more years of formal education of the household head by a factor of 0.919. One would expect low levels of literacy to hinder effective flow of information for qualitative decision-making regarding an unfamiliar technology. The mean of 11.3 years of formal education implies that on average, heads of household had attained secondary school education. This should be adequate for an individual to make an informed decision regarding the choice of a new technology. These results are contrary to some other adoption studies (Kebede et al., 1990; Brush and Taylor, 1992; Adesina and Baidu-Forson, 1995; Fleke and Zegeye, 2006), which show a positive correlation between education and the probability of adoption. The possible reason for the present results is that the education system in Uganda is less orientated towards hands-on practical training. At higher levels of training, more people opt for administrative and management-biased professions, based mainly in urban areas. Biogas technology is viewed as a technology for the less educated and rural people. A similar finding was reported by Mendola (2007), where educational level of the household head was uncorrelated with the decision to adopt an assortment of selected technologies in Bangladesh.

Gender relationships regarding male-female asset ownership and control in Africa influence key decisions regarding the uptake of biogas energy. Our results indicate that though positively correlated with the likelihood of adopting biogas energy, gender of the household head, a proxy variable for gender influence on the decision to adopt, was not statistically significant, with an odds ratio of 1.433. This suggests that households headed by women are not differently constrained from adoption of biogas technology. This is a particularly encouraging development as regards the promotion of biogas technology in an environment where women have less access to and control of resources; yet provide most of the labour required for production. Recognising that women are as important in the biogas technology adoption process as their male counterparts can be particularly instrumental in targeting women's organisations for promoting biogas technology.

In the study area, the average household comprised 8 members, which is an indication of large households, and household size significantly influenced the household's decision to adopt biogas technology. With an odds ratio of 1.222 and a logit coefficient of 0.200, a larger household had a higher probability of adopting biogas energy than a smaller one (Table 13).

The household provides production factors, especially labour for routine operation and maintenance of the biogas plant. As observed by Ji-Quin and Nyns (1996), almost all family-size digesters in developing countries have a common characteristic: the combination of biogas producer and biogas consumer, whereby family members produce biogas and they consume what they produce. This presents what Ji-Quin and Nyns (1996) refer to as a pair of contradictions - the interests of producer and the interests of consumer. They assert that the labour needed in the routine operation and maintenance of the digester is especially important when the producer and consumer are combined and therefore a large family becomes a source of labour for such tasks.

Given the space requirements of biogas technology in terms of area for setting up the biogas plant and providing pastures for the cattle needed to provide the feedstock for biogas production, the area of land owned by the household becomes a crucial factor in the adoption of biogas technology. Here, the average size of farm was 7.6 acres and 9.5 acres for biogas users and non-users, respectively. An integrated biogas unit ordinarily comprises the biogas plant, the animal unit for provision of the substrate and the fodder unit to sustain the animal unit. All these require considerable space for the biogas unit to operate effectively and efficiently. For a biogas plant to operate economically, Akinbami et al. (2001) concluded that the kitchen, animal shed for dung generation, slurry compost pit and digester must all be close together in order to reduce costs.

However, in this study increasing farm size reduced the likelihood of a household adopting biogas technology by a factor of 0.983 (Table 13). In Uganda, particularly in eastern regions where this study was conducted, households have smaller land holdings, probably making it less feasible for them to install more sustainable and integrated family-sized biogas units.

An increase in the number of cattle owned by a household increased the likelihood of a household adopting biogas by a factor of 1.202 (Table 13). In Uganda, cattle are the major source of substrate for biogas production. Other sources of substrate such as crop residues, household and industrial waste have not been fully harnessed, mainly due to limited technical skills. The number of cattle owned by a household thus has a direct impact on a number of other important decisions related to biogas utilisation. Singh and Sooch (2004) contend that selecting the size of biogas plant to be installed depends upon the number of persons to be served or the quantity of cow dung available and stress that selection of unsuitable biodigester capacity that does not match the availability of the cow dung renders the biogas technology uneconomical. Adeoti et al. (2000) found that two head of cattle per household per day were adequate for the necessary substrate required daily for gas production from a family-sized digester. Based on the results of the present study, where the average number of cattle owned by a household was 4 for biogas users and 7 for non-users, there was adequate cow dung as feedstock for family-sized digesters in Uganda. However, the commonly practised free-range system of rearing cattle could greatly affect the quantity of cow dung available for biogas production.

In Uganda, fuelwood and kerosene are the primary energy sources for cooking and lighting for the majority of the rural population (MOFEPD, 2002). Therefore, the costs of fuelwood and kerosene were included in the model and were found to be positively correlated and statistically significant ($P<0.01$) in influencing the household's decision to adopt biogas. The availability and nature of a new technology are critical factors in influencing the decision of a household to adopt it as a substitute technology. A household must be convinced that the new technology is unquestionably better than the existing technologies. The development and acceptance of biogas will therefore largely depend on the exploitation of its technological advantages over the existing technologies.

Evidence from similar adoption studies indicates that biogas technology is more attractive when the local equivalent energy price is high and when the digester is highly efficient and easy to manage (Brush and Taylor, 1992). When the price of the replaced energy is high, this positively motivates the biogas producer and user to turn to cheaper biogas energy. Similar results were reported by Ji-Quin and Nyns (1996) who concluded that for the biogas consumer, the motivation usually depends on the economic benefits obtained by replacement of traditional fuels with biogas and the modernisation and convenience of daily life. They further observed that biogas is a type of high grade fuel that offers several advantages over traditional fuels. As deforestation increases in Uganda, the cost of fuelwood is rocketing, while the price of other alternative energy sources for cooking has also increased. This increases the likelihood of households accepting biogas as a cheaper alternative energy source.

For lighting purposes, the price of kerosene is relatively high. Moreover biogas energy is regarded a more efficient, clean and convenient energy source. The chances of households adopting biogas energy on the basis of lighting cost are higher than on fuelwood cost for cooking.

Increasing household income proved to be a key factor in positively influencing a household's decision to consume biogas energy, with an odds ratio of 1.905 (Table 13). Other studies have shown similar results, with e.g. Gupta and Ravindranath (1996) stressing the impact of household income on the choice of cooking fuel. The most probable effect of income of household on adoption of biogas energy is the financial ability to install a digester system, which is often cited as the single most important factor determining whether a household adopts biogas energy. The initial investment is usually considered too high for a rural household to afford and therefore biogas digesters remain the preserve of relatively wealthier households. Our logistic regression results suggest that significant increases in income were required to cause a reasonable impact on the adoption of biogas energy. In fact, all the biogas plants included in this study were built with the assistance of donor agencies.

Household location proved to be an important factor in biogas energy production and consumption. Most biogas users were located in rural areas, where there is limited or no national electricity grid, and there were fewer biogas digesters in urban areas because of easier access to the national electricity grid and other energy sources. However, logistic regression showed that household location was not statistically significant.

4.2 The effect of user perceptions on biogas energy adoption decisions in Uganda

4.2.1 General characteristics of BCS use in Uganda

The analyses of the variables showed that out of a sample of 84 biogas user households, 58% were headed by females, 75% earned a monthly income of less than UGX 500,000, 10% earned between UGX 500,000 and 1,000,000 and 5% earned a monthly household income of over UGX 1,000,000. The results show that the biogas technology had mainly been embraced by the lower income group.

The average herd size was four cattle. Adeoti et al. (2000) found that two head of cattle per household and day in Nigeria were adequate for the necessary substrate required daily for gas production from a family-sized biodigester. On that basis, the potential existed for provision of adequate feedstock for generation of biogas for the BCS in the studied area. On average, households indicated they had used biogas technology for a period of 5.6 years, a period deemed reasonably adequate for them to fully appreciate the benefits of BCS over CCDs. More than 90% of households perceived the BCS as being superior in terms of durability of the cooking device compared with CCDs. Also in terms of taste of food prepared from the cooking device, 65% perceived the BCS as superior and in terms of reducing human drudgery burden imposed and air pollution potential of using the cooking devices by 69% and 76%, respectively. The BCS was perceived as inferior to CCDs in terms of the need for spare parts and after-sales services by 55% of the households and in terms of initial cost by 74%.

4.2.2 Effect of integrating household perceptions on adoption decisions for BCS in Uganda

The first model, the socio-economic and demographic model, considered cattle herd size owned by the household, household size, total household monthly income, household head experience in production and use of biogas, and gender of the household head as the independent variables. A positive sign on the coefficient means that an increase in that variable increases the probability of a household adopting and intensity of use of the BCS, while the converse is true for a negative sign.

A change in the probability of adoption indicates the percentage change in probability of the household adopting the BCS with one unit change in the variable. The coefficients for variables in the model do not represent the marginal effects directly but the sign of the coefficient provides information as to the direction of the effect (Oladele, 2005). For dummy variables, a marginal change indicates a discrete change of the variable from 0 to 1. The variable coefficients indicate the effect of the variables on the probability of a household adopting the BCS and intensity of use of the BCS after adoption.

Results from the model showed that all these variables except household size had a positive relationship with the probability of adoption and intensity of use of the BCS (Table 14). It appears large households' meagre savings cannot enable them to invest in new and cleaner sources of energy and have to rely on the CCDs. This makes them more unlikely to adopt biogas energy than their smaller family-size counterparts.

Experience of the household and household size were highly significant at P<0.01, while cattle herd size was significant at P<0.05. This is particularly an important factor in that households have experience in biogas production and use could act as focal points for the dissemination of biogas energy.

Table 14. Estimated empirical results for only socio-economic and demographic variables in the BCS adoption model in Uganda

Variable	*Normalized Coefficient*	*T-ratio*	*Robust Standard error*	*Elasticity of*	
				Adoption Probability	*Expected use intensity*
LIVSTOCK	1.175**	2.17	0.584	0.1178	0.105
SIZEHHLD	-1.727***	-4.29	0.410	-0.366	-0.328
INCOMHLD	6.155	1.59	3.634	0.188	0.169
BIOGEXPC	1.600***	3.68	0.460	0.246	0.221
DSEXHHLD	2.124	0.61	3.329	0.0377	0.0338
INTERCEPT	26.151***	4.44	6.799		
/lnsigma	2.552		0.087		
sigma	12.835		1.112		

*Note. ***, ** denote statistical significance at P<0.01 and P<0.05 respectively*

Number of observations = 84
LR χ^2 = 40.48
Log likelihood = -315.402
Log pseudo likelihood = -316.659
Wald χ^2 = 41.32
Censoring = 6 right-censored observations

All the variables except gender of the household head were consistent with the expected signs (Table 14). While it is mainly women who take care of cooking-related needs at home and therefore expected to positively influence biogas energy adoption, the key investment decisions in the household are still determined by men. This could explain why more male headed households have adopted biogas energy since they have the power to decide in which areas to invest. Household income, although positively related with the probability of adoption as expected, was not statistically significant. Evidence from many African countries indicates that the investment cost of even the smallest biogas unit is prohibitive for most poor African rural households (Karekezi, 2002). It seems that the cost sharing arrangement with NGOs significantly leveraged the studied households of the high initial installation cost that impedes many households from investing in biogas energy.

Decomposition of elasticity of expected value on BCS use revealed that household size exerted the greatest effect on the probability of BCS adoption and use intensities (Table 14). The total elasticity value is 0.70, comprising of 0.37 for the elasticity of adoption and 0.33 for the elasticity of use intensity. This means that a 1% increase in household size is expected to result in 0.37% decrease in the adoption component, whereas the expected use intensity decreases by 0.33%. This was followed by experience of the household head with a total elasticity value of about 0.50, household income with a value of 0.4 and size of cattle herd with 0.2, with the gender variable having the least elasticity of adoption and use intensity of 0.07 (Table 14).

The total elasticity value for experience of the household of about 0.5 is decomposed as 0.25 for the elasticity of adoption and 0.22 for the elasticity of use intensity. This means that a 10% increase in the experience of the household head is expected to result in about 5% increase in the adoption and use intensities of the BCS. Similar interpretation of results has been shown by Adesina and Zinnah, (1993) and Bamire et al., (2002). The elasticity of categorical variables shows the effects of a unit change in the specific categories on the probability of adoption and use intensity of the BCS (Adesope et al., 2007). For instance, gender variable showed an elasticity of adoption and use intensity of 0.04 and 0.03, respectively, meaning that, with all other factors held constant, a 1% increase in dissemination of BCS in the study area is expected to increase the probability of adoption component by 0.04% among the male headed households, whereas the expected use intensity increases by 0.03% (Bamire et al.2002). It should be noted that no variable recorded a total elasticity estimate of greater than one ($\varepsilon > 1$).

The second model included only user perceptions on technology-specific characteristics. All the variables with the exception of perception of the need for spares and after-sales services were significant (Table 15). Compared with the CCDs, the BCS requires more frequent replacement of spare parts and sometimes cooking utensils. The other variables in this model (perception of the durability, taste of food prepared, initial cost, air pollution impact and human drudgery burden associated with the cooking device) significantly influenced the elasticity of adoption and intensity of use of the BCS at P<0.01 (Table 15). The coefficients were also in conformity with the expected signs.

The results showed that perceptions of the taste of food prepared with the cooking device, the initial cost of the device and the human drudgery burden imposed were highly significant in influencing the probability of adoption and intensity of use of the BCS at P<0.01. However, while the perception of taste of the food positively influenced the adoption rates, the perception of the initial cost and the human drudgery burden negatively influenced the adoption rates. Any technology that is viewed as likely to reduce this burden will have a higher probability of adoption. A similar study in Nigeria found taste of food to be an important cultural trait in adoption of biogas energy (Akinbami et al., 2001).

Table 15. Estimated empirical results for perception variables of only technology-specific characteristics in the BCS adoption model in Uganda

Variable	*Normalized coefficient*	*T-ratio*	*Robust Standard error*	*Elasticity of*	
				Adoption Probability	*Expected use intensity*
DBIOGDUR	10.735**	1.91	4.201	0.267	0.226
DBIOGFTS	9.564***	2.82	3.398	0.172	0.146
DBIOGINC	-11.375***	-2.90	3.441	-0.198	-0.167
DBIOGHDR	-10.124***	-2.77	3.629	-0.193	-0.163
DBIOGSPR	-5.267	-1.39	3.479	-0.079	-0.067
DBIOGAIR	-6.764*	-1.65	3.809	-0.142	-0.120
INTERCEPT	41.052***	5.00	6.955		
/lnsigma	2. 659		0.074		
sigma	14.288		1.059		

*Note. ***, **, * denote statistical significance at P<0.01, P<0.05 and P<0.10 respectively*

Number of observations	*= 84*
LR χ^2	*= 24.73*
Log likelihood	*= -323.274*
Log pseudo likelihood	*= -324.825*
Wald χ^2	*= 33.67*
Censoring	*= 6 right-censored observations*

The human drudgery burden imposed by any device has also been shown to negatively affect adoption of that technology (Mwakaje, 2008). For biogas energy from family biodigesters, the human drudgery element is manifested through: (1) collection of animal dung, which is particularly problematic for farmers who do not keep their livestock penned in one location, and (2) small-scale farmers with small herds of livestock not being able to get sufficient biodigester feedstock to ensure a steady generation of biogas (Karekezi, 2002). This implies that such households have to transport the cow dung, increasing the human drudgery burden.

The perception of the initial cost of the cooking device was also significant in influencing the probability of the household adopting the technology. The initial cost of the cooking device is big impediment in the acquisition of that technology. Any technology therefore viewed as too expensive to be acquired will be shunned in preference for the relatively cheaper option hence the negative relationship with the probability of its adoption. This is also true for the perception of the availability of spare parts for that technology. If the spare parts of the technology are not readily available, the probability of its adoption will be low.

The air pollution perception variable included in the model assessed the importance attached by households to the impact of a cooking device on their health and environment. The results show that households perceive the BCS as more environmentally friendly than CCDs, a good indication that they know the health hazards associated with some CCDs such as the fuelwood stove. Durability of the cooking device is positively correlated with replacement and maintenance costs. If well built and maintained, the average lifespan of a family biodigester is reported to be 25 years. This allows the BCS to outcompete many CCDs. This explains why perception of durability of the BCS relative to CCDs was significant at $P<0.10$.

Results of the third model which combined both the household-specific and technology-specific attributes revealed a substantial improvement in the level of significance of the variables in the model (Table 16). Among the household-specific variables, cattle herd size increased in significance to $P<0.01$ compared with $P<0.05$ in the socio-economic model. For the technology-specific variables, perception of the need for spares and after-sales service, which was not significant, became significant at $P<0.01$ (Table 16). This shows that user perceptions of the technology characteristics significantly affect the adoption rates of biogas energy in Uganda. The results also showed that household size exhibited the highest probability of adoption and intensity in the integrated model with the gender variable registering the least impact. The superiority of the technology-specific variables in influencing adoption and use intensity was manifested through their statistical significance levels. All the perception variables were significant (Table 16).

These results are in conformity with earlier studies which show that consumers critically evaluate the characteristics of a technology or product in their adoption decisions (Adesina and Zinnah, 1993; Adesina and Baidu-Forson, 1995; Masangano and Miles, 2004; Joshi and Pandey, 2005; Adesope et al., 2007). In a study on the effects of farmers' perceptions on the adoption of modern rice varieties in Nepal, Joshi and Pandey (2005) found that an econometric model that included farmers' perception variables was superior in explaining adoption behaviour to a model that included only the usual farm and farmer-related variables.

Table 16. Estimated empirical results for perception variables of both household-specific and technology-specific characteristics in the BCS adoption model in Uganda

Variable	*Normalized coefficient*	*T-ratio*	*Robust Standard error*	*Elasticity of*	
				Adoption Probability	*Expected use intensity*
LIVSTOCK	1.835***	3.83	0.418	0.181	0.171
SIZEHHLD	-1.534***	-4.34	0.361	-0.333	-0.316
INCOMHLD	1.795	0.40	3.422	0.0609	0.058
BIOGEXPC	1.293***	3.44	0.430	0.205	0.194
DSEXHHLD	1.302	0.41	2.684	0.026	0.024
DBIOGDUR	11.353***	2.67	3.320	0.293	0.277
DBIOGFTS	7.669***	2.88	2.683	0.143	0.136
DBIOGINC	-8.450***	-2.83	2.770	0..152	-0.144
DBIOGHDR	-9.126***	-3.28	2.951	0.180	-0.170
DBIOGSPR	-7.665***	-2.61	2.547	0.120	0.113
BIOGAIR	-4.810*	-1.50	2.895	0.104	0.099
INTERCEPT	34.081***	4.29	7.076		
/lnsigma	2.377		0.079		
sigma	10.776		0.846		

*Note. ***, **, * denote statistical significance at $P<0.01$, $P<0.05$ and $P<0.10$ respectively*

Number of observations = 84
LR χ^2 = 70.83
Log likelihood = -300.227
Log pseudo likelihood = -301.930
Wald χ^2 = 126.53
Censoring = 6 right-censored observations

Farmers' perceptions of the characteristics of the rice varieties were important in determining technology choices. These results confirm our earlier hypothesis that household perceptions of the BCS significantly affect its adoption rates in Uganda.

4.3 Economic viability of biogas energy production from family-sized digesters in Uganda

4.3.1 Costs of family-sized biogas plants in Uganda

Total annual costs of the most common fixed-dome family-sized biogas plants in Uganda ($8m^3$, $12m^3$ and $16m^3$) were computed as total capital and installation costs (Table 7) plus total operational and maintenance costs as shown in Table17. Results show that the bulk of the capital costs comprise civil construction and labour costs with supply line costs constituting only about 10%. As expected, the bigger the capacity of the biogas plant, the higher the costs of installation and operating the plants. The difference stems from the additional capital and installation inputs required for larger capacity plants. The cost of dung forms the highest proportion of the total annual costs (Table 17). For biogas production to be sustainable, it is advisable that a household rears cattle to ensure a steady supply of feedstock. The high cost of cattledung can be an inhibitive factor for biogas production and use if the household is to purchase the dung.

Table 17: Estimation of total annual costs for family-sized biogas plants in Uganda

SN	*Name of component*	*Biogas Plant Capacity*		
		8m³	*12m³*	*16m³*
1	Total Dung requirement (kg)	73,000	109,500	146,000
2	Total Annual cost of dung (UGX)	3,650,000	5,475,000	7,300,000
3	Total capital and installation Costs (UGX) [From Table 7]	2,823,975	3,943,275	4,943,275
4	Annual Maintenance Costs(UGX) [4% of Capital & Installation costs]	112,959	157,731	197,731
5	Annual depreciation(UGX) [4 % of Capital & Installation costs]	112,959	157,731	197,731
6	Total operational & Maintenance (O&M) Costs (UGX) [2+4+5]	3,875,918	5,790,462	7,695,462
7	**Total Annual Costs for biogas plant (UGX) [3+6]**	**6,699,893**	**9,733,737**	**12,638,737**

Note.

(i). Average price of fresh cowdung is taken at UGX50 per kg.

(ii). Total annual cowdung cost has been estimated as: Total dung requirement x *average price of fresh dung.*

(iii). Annual dung requirement (kg) has been estimated as: Plant capacity x *25* x *365 because $1m^3$ of biogas requires 25kg of fresh dung per day.*

(iv). Annual depreciation cost has been estimated as 4 % of Capital & Installation costs (Singh and Sooch, 2004).

4.3.2 Benefits from family-sized biogas plants in Uganda

The results of the estimated total annual incremental benefits from the use of biogas show that a household derives more incremental benefits from lighting than from cooking (Table 18).

Table 18: Estimation of annual monetary benefits from family- sized biogas plants in Uganda

	Name of component	*Biogas plant Capacity*		
		8m^3	*12m^3*	*16m^3*
1.	Anticipated annual biogas production (m^3)[100% of installed capacity]	2,920	4,380	5,840
2.	Net quantity available for use (m^3) [80% of installed capacity]	2,336	3,504	4,672
3.	Net quantity available for cooking (m^3) [20% of Net quantity available for use]	467	701	934
4.	Net quantity available for lighting (m^3) [80% of Net quantity available for use]	1,869	2,803	3,738
5.	Monetary benefits from fuelwood equivalent of net available for cooking (UGX)	116,924	175,386	233,848
6.	Income from kerosene equivalent of net available for lighting (UGX)	1,268,076	1,902,113	2,536,151
7.	**Income from gas (UGX) [No.5 + No.6]**	**1,385,000**	**2,077,500**	**2,769,999**
8.	Quantity of slurry available (kg)	73,000	109,500	146,000
9.	Monetary benefits from from N value of the slurry	1,051,200	1,576,800	2,102,400
10.	Monetary benefits from from P value of the slurry	2,759,400	4,139,100	5,518,800
11.	Monetary benefits from K value of the slurry	1,095,000	1,642,500	2,190,000
12.	**Income from slurry (UGX)[No9 + No10 + No11]**	**4,905,600**	**7,358,400**	**9,811,200**
13.	**Total income [7+12]**	**6,290,600**	**9,435,900**	**12,581,199**

This is because of the higher cost of kerosene for lighting compared to the cost of fuelwood for cooking which biogas replaces. The monetary benefits from biogas for cooking are dismally low compared to the benefits from biogas for lighting (about 10% of the total benefits from lighting). As the price of fuelwood continues to increase in Uganda, for various reasons, the incremental benefits from using biogas are likely to be more pronounced. The benefits from biogas for lighting could have been much higher if another more expensive fuel for lighting had been used in valuation of the benefits because kerosene is amongst the cheapest fuels for lighting in Uganda. This therefore suggests that the benefits presented in this analysis are a bare conservative estimate of the potential benefits of biogas for cooking and lighting.

Estimated value of the total annual incremental benefits from the spent slurry show that benefits from slurry comprised over 50% out of the total annual benefits from the biogas plant (Table 18). This was followed by benefits from biogas for lighting purposes (40%), while benefits from biogas for cooking contributed only about 10% of the total annual benefits. This was mainly attributed to the high prices of the inorganic fertilizers on the local market which were used in the valuation of the slurry. This also highlights the importance of slurry as a potential source of comparatively low cost fertilizers affordable by many households if they took up biogas energy generation.

4.3.3 Economic viability of family-sized biogas plants in Uganda

4.3.3.1 Payback Period Results

Results show that the $8m^3$ biogas plant capacity had the highest undiscounted payback period (UPBP) of 1.17 years, while the $16m^3$ exhibited the lowest UPBP of 1.01 years (Table 19). This is attributed to the lower per unit cost of installation and annual operating and maintenance (O&M) costs which decrease with the increase in the capacity of the biogas plant.

Table 19: Undiscounted Payback period (UPBP) results for family-sized biogas plants in Uganda

		Biogas Plant capacity		
SN	*Name of component*	*$8m^3$*	*$12m^3$*	*$16m^3$*
1	Total annual income (UGX) [Table 5]	6,290,600	9,435,900	12,581,199
2	Total capital and installation Costs (UGX) [Table 4]	2,823,975	3,943,275	4,943,275
3	Total operational & Maintenance (O&M) Costs (UGX) [Table 4]	3,875,918	5,790,462	7,695,462
4	Total annual Profit (UGX)[1-3]	2,414,682	3,645,438	4,885,737
5	**Undiscounted Payback Period (Years) [2÷4]**	**1.17**	**1.08**	**1.01**

$$UPBP = \frac{CI}{AP}$$

Where:

UPBP = Undiscounted Pay back period

CI = Total capital and installation costs

AP = Annual Profit

Annual profit = Annual income – Annual operational cost (Singh and Sooch, 2004).

Although there is no significant difference in the UPBP for the three plant sizes, results show that as the capacity of the biogas plant increases, the UPBP decreases. This conforms to the standard practices and trends in the economics of installation and operation of any technical project (Singh and Sooch, 2004). On the basis of the UPBP results, the16m^3 plant with a shorter period was the most economically viable. This implies that a household with a 16m^3 biogas plant would take few years to recover the original cost of investment through the annual net cash revenues it generates than the other plants.

4.3.3.2 Net Present Value (NPV) Results

The NPV results for all the biogas plant capacities indicate that they are economically viable. At the base case scenario discount rate of 12%, NPV turns out positive for all the three capacities of the biogas plants and increases with increase in plant capacity (Table 20). The NPV increases with increase in the plant capacity. The slope of the change of NPV with the plant size largely depends on the discount rate. Lower rates depict a steeper change in NPV (Kandpal et al., 1991). Hence, an 8m^3 plant would be more sensitive to changes in economic parameters than the 16m^3 plant.

Table 20: Net Present Values for the Base case scenario at Discount rate of 12%

Biogas Plant capacity	*Net Present Value (Million UGX)*	*IRR (%)*
8 m^3	11.34	36.0
12 m^3	17.50	37.0
16 m^3	23.86	39.0

The positive NPV for the three plant capacities implies that all the three designs are economically viable. However, because smaller capacity designs are more sensitive to economic parameters, the 16m^3 is more economically viable.

The IRR for the three capacities of the family-sized biogas plants (Table 20) shows that IRR increases with the increase in the capacity of the biogas plants. These results show the significance of scale effect on the economic viability of family-sized biogas plants. Based on the current stream of benefits and costs, the IRR results indicate that the NPV for the 8m^3, 12m^3 and 16m^3 plant designs would be equal to zero at discount rates of 36%, 37% and 39%, respectively.

Interest rates above 36%, 37% and 39% for the respective plant designs will lead to negative NPVs, implying that the cost streams for the respective plant designs will exceed the benefits. Households should therefore refrain from borrowing at annual interest rates above 36% for the 8m^3 plants, 37% for the 12m^3 and 39% for the 16m^3 plant designs. These results show that the 16m^3 plant with the highest IRR is the most economically viable.

4.3.3.3 Sensitivity Analysis Results

Sensitivity analysis results show that a reduction of the discount rate from 12% to 6% increases the NPV significantly. Increasing the discount rate from 12% to 24% however substantially decreases the NPVs of all the biogas plants.Thus while NPV remains positive for all the three plant capacity designs; a higher discount rate greatly decreases the profitability of biogas plants. It is important to note that the 12% discount rate used in this analysis is a standard rate conventionally used in evaluating economic projects. This shows that if the interest rates in Uganda were as low as the standard rate of 12%, the profitability of family-sized biogas plants would be as high as UGX 11 million for the $8m^3$ plants, UGX 18 million for the $12m^3$ and UGX 24 million for $16m^3$ plants (Table 21).

However, the 24% discount rate which was the ongoing interest rate at the time of this study is more appropriate in portraying a realistic position of the economic performance of family-sized biogas systems. Thus the low NPV of UGX 3 million, UGX 5 million and UGX 7 million for the $8m^3$, $12m^3$ and $16m^3$ plants, respectively, give a more realistic situation of the profitability of the plants (Table 21).

Increase in the capital costs by 50% has a similar effect as the increase in the discount rate. Increase in capital costs increases the total cost of the biogas systems. When the capital costs are decreased by 50% with a discount rate of 6%; the NPV is greater than zero for all the three plant capacities. This reaffirms the fact that the biogas plants are economically viable at lower discount rates and lower capital costs. However, at a higher discount rate of 24% even when the capital costs are reduced by 50%, only the $8m^3$ biogas plants remain viable. This implies that capital costs significantly affect the economic viability of family-sized biogas energy production.

Table 21. Sensitivity analysis results for the selected economic parameters

Capacity of biogas Plant	*NPVs (Million UGX) for different discount rates*			
i) Increase and decrease in discount rates from 12% to 24% and 6%, respectively				
	6%	**12%**	**24%**	**IRR (%)**
8 m^3	21.00	11.34	3.23	36.0
12 m^3	32.08	17.50	5.25	37.0
16 m^3	43.40	23.86	7.44	39.0
ii) 50% increase in capital costs				
8 m^3	19.58	9.92	1.81	30.0
12 m^3	30.11	15.52	3.28	31.0
16 m^3	40.93	21.38	4.97	32.0
iii) 50% decrease in capital costs				
8 m^3	22.42	12.75	4.64	46.0
12 m^3	34.05	19.47	7.22	47.0
16 m^3	45.87	26.33	9.91	48.0
iv) 50% Increase in O&M costs				
8 m^3	-3.17	-5.08	-6.69	1.0
12 m^3	-0.61	-4.80	-8.32	5.0
16 m^3	-4.58	-8.73	-12.22	2.0
v) 50% Decrease in O&M costs				
8 m^3	45.16	27.75	13.13	91.0
12 m^3	68.18	42.02	20.05	95.0
16 m^3	91.38	56.44	27.11	99.0

The higher capacity plants register negative NPV implying that biogas plants are less viable at higher capital cost. It is thus noted that the 8m^3 biogas plants (smaller capacity plants) register higher NPV compared to their larger counterparts because of the level of capital investments sunk in these plants. When capital costs are decreased by 50%, the higher capacity plants still register lower NPV than smaller ones.

The most important sensitivity parameter is the O&M costs. The greatest effect is registered when O&M costs are increased by 50% where for all discount rates (6 -24%), all the three biogas plant capacities register negative NPV, making all of them not economically viable, of course with higher capacity plants registering even lower NPV. The corresponding IRR is lowest when the O&M costs are decreased compared to all the other scenarios (Table 21). This highlights the effect of O&M cost on the viability of biogas plants.

Attention needs to be paid to critical inputs required in the day to day operations of the biogas plants, such as fresh dung and labour for operating the plant, which can lead to sudden increase in O&M costs. This greatly affects the profitability of biogas energy production. Results show that when the O&M costs are decreased by 50%, NPV almost doubles (Table 21). Households wishing to invest in biogas energy production should be very certain about the reliability of their source of raw materials especially cowdung if they are to ensure sustainable profitability of their biogas production systems.

Break-even sensitivity analysis results are presented in Table 22. These results highlight critical levels and rates at which family-sized biogas systems in Uganda should operate and/or borrow if they are to remain economically viable.

The IRR results show that NPV of the biogas plants will remain positive at various interest rates below 35%, 37% and 39% for the respective plants, and beyond which the NPV become negative. Households should not borrow to invest to invest in their biogas systems at interest higher than 36% per year for the 8m^3 biogas plant, 37% for the 12m^3 and 39% for the 16m^3 plants. The cost structure of the biogas systems offers useful guidelines to households about which levels they should operate in order to remain economically viable. The break-even sensitivity results suggest that at 12% discount rate, total costs should not exceed UGX 18 million for the 8m^3 plants, UGX 27 million for the 12m^3 and UGX 37 million for 16m^3 plants (Table 22).

Table 22. Sensitivity and Break-even Analysis results at 12% and 24% discount rates

	Biogas Plant capacity		
Name of component	*8m^3*	*12m^3*	*16m^3*
i) At 12% discount rate:			
Total costs at break-even point (Million UGX)	18.04	27.23	36.49
Total (O&M) costs at break-even point (Million UGX)	5.39	8.13	10.89
ii) At 24% discount rate:			
Total costs at break-even point (Million UGX)	6.29	14.98	20.08
Total (O&M) costs at break-even point (Million UGX)	4.66	7.07	9.51

Likewise, the total operating and maintenance (O&M) costs should not exceed UGX 5 million for the $8m^3$ plants, UGX 8 million for the $12m^3$ and UGX 11 million for $16m^3$ plants if the plants are to remain profitable. These expenditure levels reflect the break-even points (where the respective NPV are equal to zero) for the respective biogas plants at the discount rate of 12%. Beyond these levels, the biogas systems register losses; the NPV becomes negative.

At the discount rate of 24%, break-even sensitivity results reveal that total costs should not exceed UGX 6 million for the $8m^3$ plants, UGX 15 million for the $12m^3$ and UGX 20 million for $16m^3$ plants (Table 22). The total operating and maintenance (O&M) costs should not exceed UGX 5 million for the $8m^3$ plants, UGX 7 million for the $12m^3$ and UGX 10 million for $16m^3$ plants. These results show that the break-even points for the biogas systems occur at relatively higher total and O&M costs with lower discount rates (12%) compared to the high rates (24%). Households should thus monitor the cost levels for the respective plants to avoid incurring losses.

4.4 Biogas energy Estimates from animal wastes in Uganda

4.4.1 Animal wastes and biogas energy potential in Uganda

The major livestock types reared in Uganda with the potential for generating wastes for biogas energy production include cattle, goats, pigs, sheep and poultry (chicken, ducks and turkeys). The wastes of these livestock types are the major source of substrate for biogas energy production in Uganda. Livestock in Uganda is predominantly an economic activity for the small-holder farmers who own about 90% of the livestock in Uganda (Pandey et al., 2007). The exotic/crossbreed cattle estimated at 8.5% of the total cattle population represent the livestock type with the highest potential for biogas production (MFPED, 2002). The number of households who reared exotic/crossbreed cattle in Uganda in 2002 is shown in Table 10. It is estimated that about 50,000 households with at least two exotic/crossbreed cattle have the potential of producing biogas energy from livestock dung (Pandey et al., 2007). Different international organizations such as Heifer Project International, Send a Cow-Uganda and DANIDA have promoted dairy farming in Uganda. They have tremendously increased the number of exotic zero grazing dairy cattle in the country hence boosting the potential for biogas energy production.

The exotic cattle are mainly concentrated in the south west and in few districts in central and eastern Uganda (Pandey et al., 2007). The geographical spread of the potential areas for biogas production is expected to follow the areas with the highest concentration of zero-grazing units. Except for the eastern region which does not have households with more than 500 head of exotic/crossbreed cattle, the rest of the regions have the potential to produce biogas energy on a large-scale.

A total of 5.8 million head of indigenous cattle was reared in 2002 (MFPED, 2002). Indigenous cattle are concentrated in eastern Uganda where the semi-zero grazing system is used. With this system, only the cattle dung produced at night and during milking can be used as input for the biogas plant, since dung deposited when the cow is grazing is too labor-intensive to collect.

Households with at least 5 indigenous cattle are considered potential biogas producers (Panday et al., 2007; Singh and Sooch, 2004; Akinbami, 2001; Adeoti, 2000), since useable dung production is reduced by more than half (Pandey et al., 2007).

Pig manure can also be a good source of substrate for biogas production. Households with 10 or more pigs are regarded potential biogas producers (CAEEDAC, 1999). More than 5,000 households were reported to be raising at least 10 pigs (MFPED, 2002). Poultry droppings can be a good source of substrate for biogas production. At least 300 chickens are needed to sustain a $6m^3$ biogas unit (Pandey et al., 2007). Sheep and goat dung too is a good source of substrate for biogas production.

In assessing potential biogas energy that can be generated, the issue of availability of reliable sources of substrate is crucial. Several studies have discussed the importance of adequate animal wastes for effective and efficient performance of biogas energy production (Akinbami, 2001; Adeoti, 2001; Ni and Nyns, 1996).

The critical issue here is the amount of animal wastes required for specific digester size to operate at full capacity. Scarcity of animal dung as substrate for biogas production has been cited as one of the key factors contributing to the high failure rates of household biogas units (Singh and Sooch, 2004; Sinha and Kandpal, 1990; Akinbami, 2001; Adeoti, 2001; Ni and Nyns, 1996).

Based on the exotic or crossbreed cattle populations, there is a higher potential for availability of animal wastes for biogas energy production in the western, eastern and central regions of the country. However, depending on the feeding systems and animal wastes collection methods, the current indigenous livestock numbers can also generate adequate animal wastes for biogas production.

Water availability issues are equally important when assessing the potential of biogas energy production from animal wastes. Equal amounts of water and dung need to be fed into the digester for efficient biogas plant operation. At least 60 litres of water are required for a cow per day as well as 60 litres to put in the biodigester (Mwakaje, 2008; Rutamu, 1999). In terms of water availability, Uganda has marked differences between urban and rural populations and between geographical regions but more than 76% of households have water within one kilometer from their homes (Pandey et al., 2007). This shows that except in few semi arid areas, biogas energy production from animal wastes can be sustained by most households with adequate numbers of livestock.

Acquisition of dung for the substrate, water for mixing the dung, feeding the digester, regular maintenance, supervision, storage and disposal of the slurry, biogas distribution and utilisation, are some of the different Operational & Maintenance (O&M) costs associated with successful running a biogas plant (Kandpal et al., 1991). Total O&M costs often include the sum of operating labour costs, feedstock costs, feedstock transportation costs and maintenance costs (Gupta and Ravindranath, 1997). In Uganda, the tasks of collecting water and dung, stirring and feeding the substrate into the digester, are largely performed by household members to whom the family-sized biogas plant belongs. The average household size in rural areas is 7.6 (Walekhwa et al., 2009) and 4.2 in urban areas (MFPED, 2002). This is the major source of labour for performing the required tasks for biogas energy generation.

4.4.2 Biogas energy Estimates in Uganda

The total biogas energy potential and recoverable energy potential from livestock population estimates were calculated by use of the Organization for Economic Cooperation and Development (OECD) methodology (Tasdemiroglu, 1988). The total biogas energy potential from animal wastes was estimated to be 1740ktoe. Of this, 1189ktoe is the total energy potential from cattle wastes, 490ktoe from sheep and goats, 48ktoe from pigs and 13ktoe from poultry. At 30% recoverable rate, the total recoverable energy potential was assessed to be 523ktoe, out of which 357ktoe (68%) is from cattle waste, 147ktoe (28%) from sheep and goats waste, 15ktoe (3%) from piggery wastes and 4ktoe (1%) is from poultry dung (Table 23).

Table 23. Total and recoverable biogas energy potential from animal wastes in Uganda

Animals	*Total number of animals (thousand head)*[1]	*Coefficient of conversion*[2] *(ktoe per thousand animals)*	*Total energy potential (ktoe)*	*Recoverable*[3] *energy potential l (ktoe)*
Cattle	7,118	0.167	1189	357
Sheep and goats	1,0204	0.048	490	147
Pigs	2,183	0.022	48	15
Poultry	5,404	0.0024	13	4
Total			**1740**	**523**

1= Current livestock population estimates are based on 2002 National population Census statistics (MFPED, 2002).

2=Organization for Economic Cooperation and Development (OECD) method (Tasdemiroglu, 1988).

3=Percentage of recoverable energy was taken as 30% for all kinds of animals (Tasdemiroglu, 1988).

The results presented above only shows estimates of theoretically available animal wastes used to estimate the potential biogas energy that could be generated in Uganda. It is important to note that there are other types of livestock wastes in Uganda such as donkey, horses and camel waste, buffalo wastes, rabbit waste and other animal wastes. These wastes were not included in this analysis because of lack of statistical data. Given the theoretical livestock population estimates extrapolated from the available statistical data, which may not vary much from the true population estimates, there are adequate quantities of animal wastes for sustainable biogas production and utilization in Uganda. However, this energy potential can only be harnessed if the major bottlenecks to biogas energy production have been addressed.

4.4.3 Constraints to biogas energy production and utilization

The most important constraint hindering biogas technology in the developing countries has been the cost of digester plants (initial cost of investment); difficulty in installing them and difficulty in acquiring spare parts (Mwakaje, 2008; Akinbami, 2001). A concrete digester plant installed for an average family in Vietnam varied from US$180 to 340 (Van, 1989). In Tanzania, the average cost of a biogas biodigester ranged from US$435 to US$538 (Mwakaje, 2008).

The most probable effect of income of household on adoption of biogas energy is the financial ability to install a digester system, which is often cited as the single most important factor determining whether a household adopts biogas energy (Walekhwa et al., 2009). Given that most of the rural households are subsistence farmers and given the present investment and annual running costs, owning a biogas plant is equated to acquisition of a prestigious item which can only be financed from excess funds (Akinbami, 2001). Biogas plants can therefore be seen to be a preserve for only rich households.

There is strong evidence that in most developing countries where biogas programmes have developed quickly it is because of substantial support from governments and aid agencies (Marchaim, 1992; Mwakaje, 2008; Omer and Fadalla, 2003), and when the number of subsidies from governments are reduced, the number of plants built each year reduces dramatically (Desai, 1992). Many countries such as Vietnam, Cambodia, Bangladesh, Tanzania and Uganda promoted the low-cost tubular (plastic) digester with the aim of reducing the production cost by using local materials and simplifying its installation and operation (Austin, 2003; Hieu et al., 1994; Mwakaje, 2008; Pandey et al., 2007; van Buren, 1980).

Inadequate expertise for construction and maintenance of biogas plants is often cited as one of the major constraints hindering biogas technology in the developing countries. When complications have arisen in the functioning of the plant, a common complaint articulated is that there is lack of technical support (Erdogdu, 2008, Mwakaje, 2008). The repair and maintenance requirement of the digesters usually consist of mainly the cost of maintenance and replacement of gas valves, lamp and cooking stove parts and fixing gas leakage points. Technical expertise is also paramount when selecting the right site for the biogas plant to ensure proper functioning of the plant. Proper site selection and construction will allow for easy feeding of the digester and flow of the slurry. Some studies stress that whether at the local, regional or community level, selection of the right location for biogas development is very important (Walekhwa et al., 2009). Polprasert et al. (1986) assert that a major operational problem for biogas plants was mainly excessive scum accumulation in the digester due to low specific gravity of the plant substrates arising from poor construction of the plant. Also emptying the digesters of accumulated solid particles after every about five years is required for the plant to achieve the maximum lifespan.

There is a problem of selection of unsuitable households for demonstration purposes which has resulted in low feedback from the households on technologies of installing, maintaining and repairing the digesters. The selection of demonstration farms is important to provide a high degree of household participation in digester introduction and dissemination and providing technical feedback. Policy makers must recognize that households are not homogeneous and that some households may require having biogas plants just for prestigious reasons. First priority should be given to those in greatest need in order to obtain the greatest impact from the technology.

Land area owned by the household is expected to have a positive effect on the decision to adopt biogas. A biogas plant requires some considerable amount of residential space. An integrated biogas unit ordinarily comprises the biogas plant, the animal unit for provision of the substrate and the fodder unit to sustain the animal unit. All these require considerable space for the biogas unit to operate effectively and efficiently (Walekhwa et al. 2009). If it is to operate economically, the kitchen, animal shed for dung generation, slurry compost pit and the plant must all be together (Akinbami, 2001).

Both theoretical and empirical studies of adoption show a positive association between farm size and the probability and extent of adoption (Brush and Taylor, 1992).

Insufficient dung availability and /or competitive uses for the dung have often resulted in the disseminated biogas plants being quickly abandoned by households because of their inability to meet the cooking and lighting needs (Bhat et al., 2001) The number of cattle owned by a household thus has a direct impact on a number of other important decisions related to biogas utilisation. Singh and Sooch (2004) contend that selecting the size of biogas plant to be installed depends upon the number of persons to be served or the quantity of cow dung available and stress that selection of unsuitable biodigester capacity that does not match the availability of the cow dung renders the biogas technology uneconomical.

In some rural communities, socio-cultural beliefs influence acceptability of biogas technology (Omer and Fadalla, 2003). These may include fear of abandoning a well-known technology for the unknown, the belief that food cooked by use of fuelwood tastes better than that by biogas energy. The availability and nature of a new technology are critical factors in influencing the decision of a household to adopt it as a substitute technology. A household must be convinced that the new technology is unquestionably better than the existing technologies. The development and acceptance of biogas will therefore largely depend on the exploitation of its technological advantages over the existing technologies (Walekhwa et al., 2009).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Literature on socio-economic evaluation of biogas energy has expanded and the body of knowledge in this area is increasing. This thesis makes a contribution to the already existing body of literature in this field. On the basis of these study findings, it can be concluded that biogas energy production and utilization in Uganda is both viable and sustainable. Empirical results are in conformity with the hypotheses that guided this study that a number of socio-economic factors influence biogas production and utilization, and biogas production is a profitable and sustainable venture in Uganda. However, one specific nature of most studies in the area of socio-economic evaluation of production and utilization is that most of them are location specific and cannot be accurately extrapolated to different levels. These results should therefore be used in this context. The findings have important policy implications in that they point out some policy interventions that could bolster biogas energy production and utilization in Uganda. The following conclusions are drawn from this thesis:

The study shows that socio-economic factors significantly influence biogas technology adoption decisions of households in Uganda. Specifically, the probability of a household adopting biogas technology increases with decreasing age of head of household, increasing household income, increasing number of cattle owned, increasing household size, male head of household and increasing cost of traditional fuels.

In contrast, the likelihood of adoption decreases with increasing remoteness of household location and increasing household land area. These factors should therefore be considered important in the popularisation of the technology.

User perceptions of a given technology have been found to play a key role in influencing adoption of the technology. The study investigated the current situation of household perceptions of and preferences for biogas energy in order to gain a deeper understanding of the barriers to its production and utilization in the country. Particular focus was on the biogas cooking stove (BCS), one of the most popular biogas technologies being promoted in the country. Household user perceptions of and preferences for the BCS, particularly users' perceptions of the durability of the BCS, the taste of food prepared on the BCS, initial cost of the stove, the human drudgery burden imposed by the cooking device and perception of the air pollution potential of the device had a significant influence on its adoption and use intensity rates.

Biogas energy production in Uganda is economically viable based on the three economic decision criteria used in the study. Costs of civil construction and labour costs form the biggest proportion of the initial capital and installation costs. The study also showed that the profitability of biogas plants is greatly affected by variation in discount rates and capital and O&M costs. This highlights the effect of capital and O&M costs on the viability of biogas plants. Attention needs to be paid to the reliability and affordability of the critical inputs required in the day to day operations of the biogas plants. Once the biogas plant has been set up, maintenance costs are low enough to be afforded by many households. The most economically viable levels for family-sized biogas plants in Uganda have been established. The study further established that there is adequate quantity of animal wastes for sustainable biogas production and utilization in Uganda. The total biogas energy potential from animal wastes was estimated to be 1740ktoe. Of this, 1189ktoe is the total energy potential from cattle wastes, 490ktoe from sheep and goats, 48ktoe from pigs and 13ktoe from poultry. At 30% recoverable rate, the total recoverable energy potential has been assessed to be 523ktoe, out of which 357ktoe (68%) is from cattle waste, 147ktoe (28%) from sheep and goats waste, 15ktoe (3%) from piggery wastes and 4ktoe (1%) is from poultry dung. These biogas energy potential statistics are handy for the proper planning and potential investment in this sector.

5.2 Policy Recommendations

This study showed that socio-economic and demographic characteristics of households are important determinants of biogas adoption behaviour. The negative correlation of age of household head with the adoption of biogas technology is crucial regarding the categories of households to be targeted. Organizations involved in the promotion of biogas technology should note that the younger generation is central in the biogas technology transfer process. This generation should also be brought on board in the biogas energy planning and development process in order to achieve a greater dissemination coverage and impact of the technology. This could be achieved through promotion of biogas energy use in both primary and secondary schools so that the young generation appreciates the advantages of this source of energy early enough.

The location of biogas digesters where the full benefits of the biogas system can be tapped is critical in the adoption of the technology. In Uganda, biogas energy has mainly been promoted by NGOs that target rural areas, where they think this technology could have the greatest impact. However, the results of the present study reveal that the likelihood of adopting biogas energy is greater in urban areas. Refocusing NGO programmes to include urban areas could thus create a greater impact on the intended beneficiaries. Some studies have also indicated that whether at the local, regional or community level, selection of the right location for biogas development is very important (Ni and Nyns, 1996).

Considering the long-term benefits of biogas technology, both economically and environmentally, vis-a-vis the low incomes of most potential beneficiaries who cannot afford the initial investment costs, it may be necessary to introduce some financial and non-financial incentives to promote its adoption. Such incentives may include provision of low cost credit, subsidies or financial aid to the adopters in order to share the economic burden of the investment with the household. This can be implemented with the help of government institutions such as commercial banks, microfinance institutions such as Savings and Credit Cooperative Organisations (SACCOs), local government councils, NGOs, rural community development agencies and the private sector.

The institutional framework for the popularisation and coordination of biogas technology in the country needs to be strengthened. At grassroots level, there is need to go beyond simply looking at the socio-economic and demographic attributes of individual households and support the adopters of biogas technology through improved infrastructure including support services, financial incentives, technical information and research and development in the sector. After installation of biogas systems, government and donors are rarely available to provide the technical support required in maintaining these systems. This creates an ownership gap for the installed systems and consequently, the systems break down completely or are abandoned altogether. An umbrella body, for instance the National Integrated Biogas Development Programme, should be set up to create a broad social network for the stakeholders and stimulate the exchange of experiences between biogas users and other social groups.

The National Biogas Development Programme could, for instance, be charged with the responsibility of coordinating follow-up services required after installation of the technology. There is need for quality and adequate follow-up services to the beneficiaries. Reliable follow-up services by the technical staff and agencies involved in the dissemination of the biogas technology are essential to ensure high levels of performance and acceptance of biogas plants. Follow-up services will ensure that technical-related problems are quickly detected and rectified. This should be coupled with continuous training of the technicians and households in construction and day-to-day maintenance of the biogas plants. Follow-up services are also important to provide a high degree of household participation in digester introduction and dissemination and to provide technical feedback.

The study underscores the importance of household user perceptions in biogas technology uptake. The user perceptions found to have a significant relationship with the probability and use intensity of biogas technology like perception of the durability of the Biogas Cooking

Stove (BCS), the taste of food prepared on the stove, initial cost of the cooking device, the human drudgery burden imposed by the device and perception of the air pollution potential of the cooking device, should be particularly targeted in biogas technology design and development. This calls for continuous monitoring of the ever changing user perceptions to get feedback and timely communication of this information to technology designers.

In order to remain economically viable, households need to constantly monitor the cost structure of their biogas systems through accurate financial record keeping. Given that the commercial interest rate in Uganda is about 24% for short-term loans, households need to ensure that the total costs for the plant should range between UGX 6 million and UGX 20 million per year, depending on the size of the plant. The corresponding operating and maintenance (O&M) costs should lie between UGX 5 million to UGX 10 million. Beyond these operational levels, family-sized plants in Uganda are not economically viable. This study reveals that for biogas energy from family-sized plants to be sustainable, a reliable and low-cost source of raw materials must be guaranteed. The economic viability of biogas systems in Uganda is greatly affected by variation in the O&M costs. There is thus need for an efficient and effective way of collecting and utilizing cattle dung resource to ensure sustained biogas sufficiency and reliability. One of the most feasible ways is to ensure that the prospective biogas producers possess a sufficient number of cattle.

5.3 Contributions of the thesis

Despite its long history, biogas energy has failed to get a foothold in Uganda. The first objective of this study contributes to the body of literature dealing with factors influencing household biogas technology adoption decisions by identifying and examining socio-economic factors that affect biogas energy production and utilization decisions in Uganda. From the research and development policy perspectives, while the technical attributes of the technology are crucial in influencing adoption decisions of a given technology, this study has identified and examined some socio-economic factors that influence biogas energy adoption decisions of households in Uganda. These factors could be a springboard for all organizations, private or public, involved in the promotion and development of biogas technology in the country.

Economic incentives (or disincentives), although important, are not the only driving force behind adoption of a given technology. Household fuel choice also depends on other factors, which makes knowledge of other determinants of households' choice of fuel important. Therefore to obtain an appropriate strategy to overcome the barriers and the problems in the adoption of biogas technologies, the current situation of household energy perceptions and preferences had to be investigated since any attempt to shift households to better quality fuels requires an understanding of the user perceptions and preferences of the current fuels. This is because unless the energy option is well accepted by society, it has little chance of successful implementation regardless of its technical and economic merits. The second objective of this study makes a contribution to this body of literature. The user perceptions found to have a significant relationship with the probability and use intensity of biogas technology in Uganda have been established and examined. An assessment of biogas energy use perceptions and preferences of households in Uganda could help to develop and disseminate biogas energy devices with attributes easily accepted by the society. These biogas energy user perceptions and preferences can be incorporated with the socio-economic variables that were identified and examined to boost adoption rates of biogas energy in Uganda.

Large-scale investment in biogas energy technology requires first an assessment of the economic viability of the technology as an alternative energy source. An economic appraisal of the technology is required to quantify the significant benefits and costs accruing to biogas energy production and utilization. The third objective of the study contributes to the availability of this much required financial and economic information on which planning and investment decisions in this energy sector can be based.

Among the key factors to be considered, sustainable biogas energy production largely depends on the availability of reliable and affordable sources of raw materials (substrates) for production of biogas energy. Based on the available conversion technologies, only cowdung is currently the major feedstock for the production of biogas energy in Uganda. The statistical invisibility of biogas energy potential greatly affects proper planning and potential investment in the biogas energy sector. The last objective of the study attempts to show the potential biogas energy that can be produced from animal wastes based on theoretical livestock populations in Uganda. This is a good indicator of the sustainability of biogas energy production and utilization in Uganda.

5.4 Areas for further research

Uganda is endowed with different energy sources yet the country continues to experience acute energy supply shortages. This is because of the heavy reliance on few traditional energy sources for her energy supply. Biogas energy could augment the few traditional energy sources especially for household cooking and lighting. This study focused on the socio-economic factors that influence the production and utilization of biogas energy from family-sized digesters in Uganda. The study specifically focused on the fixed dome family-sized digesters. It is therefore necessary that research work presented in this thesis be extended to the floating drum and tubular family-sized biogas plant designs as well. Research into alternative viable biogas plant designs that are within the financial reach of households could go a long way in disseminating biogas technology and alleviating the current energy shortages in the country.

The viability of larger biogas plants also needs to be highlighted. Commercialization and increased viability could be achieved through establishment of larger biogas plants, especially community-based biogas plants that could benefit larger groups of the population, particularly in rural communities. The larger community size biogas plants would hopefully provide useful energy for cooking and lighting at a much lower cost than that provided by family-sized biogas plants studied in this thesis. The high capital and installation cost of establishing numerous family sized plants could also be significantly reduced through building medium or large-scale biogas digesters in places where raw materials and technology are available and distributing the biogas to the households within the community through pipes or gas cylinders.

Uganda has rich biomass resources mix including crop and animal residues and wastes. These biomass resources are potentially rich substrate sources for biogas energy production. However, only animal wastes are used as substrate for biogas generation in Uganda. Research into the possibility of other feedstock, especially crop residues and human waste, for production of biogas energy other than cowdung is also recommended. This will help to diversify the sources of substrate for biogas energy production in Uganda.

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Appendix 1

QUESTIONNAIRRE FOR SOCIO-ECONOMIC ASSESSMENT OF VIABILITY OF BIOGAS PRODUCTION AND UTILIZATION IN UGANDA

FOR: RESPONDENTS WITH BIOGAS UNITS

1. Socio-demographic Characteristics

a) Name of Interviewer………………………………... Date………………………………

b) Name of Interviewee…………………………………. *(Optional)*

c) Sex of household head *(For Household owned biogas units) (1. Male 2.Female)*

d) No. of females/males *(For Group/Community owned biogas units) (..………F ………M)*

e) Age of household head *(For Household owned biogas units) (………………………)*

f) Education level of household head *(For Household owned biogas units)*

(1. Never had 2. Primary 3.Secondary 4. Diploma 5.University degree)

g) Location of household ……………………………….. *(1. Rural 2. Urban)*

Village name …………………………………………… Parish name……………………….

Sub county ……………………………………………… District………………………………

h) Size of household ………….. ……………….. …. *(Adults……… children…………)*

i) Major source of income to household …………… *(1. Civil service 2. farming*

3. Business 4. Other- Specify ………………………………………………………..)

j) Other source (s) of income to household ……… *(1. Civil service 2. farming 3. Business 4.Other –specify………………………………………………………………….)*

k) In which average monthly income bracket do you fall?

l) *i) Less than 100,000 ii) 100,000- 500,000 iii) 500,001- 1,000,000*

iv) 1,000,001 - 1,500,000 v). 1501, 000- 2,000,000 vi) Over 2,000,000

2. If you are involved in farming, state three major food crops and three major cash crops you grow.

Crop	Acreage(last season)	Yield last season	Proportion sold
Food crops			
a)			
b)			
c)			
Cash crops			
a)			
b)			
c)			

3. Are you engaged in biogas production? *(1. Yes. 2. No)*
   i) If yes, when did you start? *(Year……………………………………..)*
   ii) Who initiated the idea of biogas production to you? *(1.own initiative 2. NGO 3. Government 4. Other –specify ……………………………………………………………..)*
   iii) What was the major reason for starting up a biogas unit?
   (1.Domestic consumption 2. demonstration purposes 3. commercial purposes [sell] 4.Other –specify………………………………………………………………… ……………..)
   iv) What was the source of initial capital for constructing the biogas plant(s)?
   (1.Own savings 2. NGO support 3. Government support 4. Community resources 5.Cost sharing with NGO/Government 6. Other –specify……..……………………………………)

4. If cost sharing, state what exactly you, NGO or Government contributed in terms of the following:

(Fill in where appropriate)

Item	*Your Contribution*	*NGO contribution*	*Government Contribution*
a) Bricks			
b) Sand			
c) Cement			
d) PVC Pipes			
e) Gas holder/drum			
f) Plastic bag/tubes			
g) Iron bars			
h) Technical/Masonry services			
i) Initial waste for substrate			
j) stove			
k) Lamp			
l) Gas pipes and fittings			
Other-specify:			
m)			
n)			
o)			
p)			

5. How many biogas plants do you own? *(………………………… …........................)*

i) Type of ownership *(1. Private individual, 2 .Local Community 3. institutional 4. Other –specify ……………………………………………….,,…...)*

ii) If privately owned, is the biogas plant(s) located on your land? *(1. Yes………. 2. No……..)*

iii) If yes, what is the total acreage of land on which it is located? *(………………... acres)*

iv) How far is the biogas plant from your homestead? *(……………………….. kms)*

v) What biogas plant design(s) do you own? *(1. Fixed dome 2. Floating drum 3. Tubular)*

vi) *What is the installed capacity for the plant(s)? (……………………………………………….)*

6. Is the biogas plant(s) operational? *(1. Yes…… 2 . No……...)*

i) If No, has the biogas plant ever worked before breaking down? Yes/No

ii) For how long did it work before breaking down completely? *(…………………………years)*

iii) What are the reasons for the biogas plant not being operational?

a) ……………………………………………………………………………………………

b) ……………………………………………………………………………………………

c) ……………………………………………………………………………………………

d) ……………………………………………………………………………………………

e) ……………………………………………………………………………………………

7. If biogas plant is operational, for how long has it been functioning? *(………………years)*

i) What type of substrate do you use for generating biogas? *(Tick where appropriate)*

Animal waste	Household waste	Crop residues	Industrial waste/By-products
1.cattle dung *2.Chicken droppings* *3 Sheep droppings* *4. Goat droppings* *5. Pigs dung*	*1.Food waste* *2. institution food waste/ residues from: schools, hospitals, prisons and army, etc*	*1.Maize stalk* *2. Rice straw* *3.Maize cobs* *4.G/nut shells* *5.Municipal garbage* *6.Grass trimmings* *7.Forestry residues*	*1.Breweries* *2.Distilleries* *3.Bakeries* *4.Confectionaries* *5.Rice&Maize mills* *6.Abattoirs* *7.Fish factories*

ii) Give reasons for the choice of source of substrate you are using

a) ……………………………………………………………………………………………

b) ……………………………………………………………………………………………

c) ……………………………………………………………………………………………

d) ……………………………………………………………………………………………

e) ……………………………………………………………………………………………

iii) Are you aware of any other sources that can be used as substrate for biogas ? *(1.Yes 2. No)*

iv) If yes, how did you learn about the other sources of substrate? *(1. NGO 2. Fellow Biogas producers 3. Biogas Technicians 4. Government extension workers 5. Literature review 6 . internet search 7. other- specify……………………………………….)*

v) Why don't you use the following sources of substrate for biogas production?

Animal waste	Household waste	Crop residues	Industrial waste/By-products
Reasons ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ……………………….. ………………………... …………………………	*Reasons* ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ……………………….. ……………………….	*Reasons* ……………………….. ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ……………………….. ……………………….	*Reasons* ……………………….. ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ………………………… ……………………….. ………………………. ………………………..

vi). Indicate the quantity of the waste you use *daily/ weekly /monthly*

Animal waste	Household waste	Crop residues	Industrial waste/By-products

vii) Where do you obtain the waste you use as substrate in the production of biogas?

(1. own farm 2. Neighbors' farm 3. Buy from farmers 4. Own kitchen 5. Factories/Processing /industrial units (6. other- specify ……………………………..….)

viii) If you obtain waste from your own farm, state the type and number for each livestock category you own.

Cattle	No.	Pigs	No.	Sheep	No.	Goats	No.	Chicken	No.	Ducks	No.
Bulls		*Boars*		*Rams*		*He-goats*		*Local*		*Local*	
Cows		*Sows*		*Ewe*		*She-goats*					
Steers		*Steers*		*Lambs*		*Kids*		*Exotic*			
Calves		*Piglets*									
Total											

ix) Is the animal waste you get from your farm adequate? *(1.Yes 2. No.)*

x) If inadequate, where do you get supplementary waste? *(1. Neighbors' farm 2. Collect free of charge from farmers 3. Buy from farmers 4. other-specify…………………………………)*

xi) How far is the location of your biogas plant from the source of substrate? *(……………Kms)*

xii) Do you transport the waste to the biogas plant? *(1.Yes 2. No…….)*

xiii) If you do, what means of transport do you commonly use?

(1………………………….……. 2……………………………… 3 ……………………………..)

ix) State the major problems you encounter during transportation of waste to the biogas plant?

a) …………………………………………………………………………………………………

b) …………………………………………………………………………………………………

c) …………………………………………………………………………………………………

d) …………………………………………………………………………………………………

e) …………………………………………………………………………………………………

8. What do you use the biogas for? *(1.cooking 2. lighting 3. slurry 4. other-specify……………….)*

i) If you use it for cooking, state at least three common foods often cooked using biogas energy and the duration each food takes to get ready.

Food *Duration (minutes/hours)*

a) …………………………………………………………………………………………………

b) …………………………………………………………………………………………………

c) …………………………………………………………………………………………………

d) …………………………………………………………………………………………………

e) …………………………………………………………………………………………………

ii) State the major items/utensils/accessories with their respective costs that one must procure in order to use biogas for cooking when the biogas plant starts operating.

Item *Cost/Price*

a) …………………………………………………………………………………………………
b) …………………………………………………………………………………………………
c) …………………………………………………………………………………………………
d) …………………………………………………………………………………………………
e) ………………………………………………………………………………………………….

iii) What major problems have you experienced when using biogas for cooking?

a) …………………………………………………………………………………………………
b) …………………………………………………………………………………………………
c) …………………………………………………………………………………………………
d) …………………………………………………………………………………………………

iv) If you use biogas for lighting, how many lamps on average, do you use per day?*(……………)*

v) For long do you use biogas for lighting per day? *(………………….. hours)*

vi) State the major items/appliances with their respective costs that one must procure in order to use biogas for lighting when the biogas plant starts operating

Item *Cost/Price*

a) …………………………………………………………………………………………………
b) …………………………………………………………………………………………………
c) …………………………………………………………………………………………………
d) …………………………………………………………………………………………………
e) …………………………………………………………………………………………………..

vii) What major problems have you experienced when using biogas for lighting?

a) …………………………………………………………………………………………………
b) …………………………………………………………………………………………………
c) …………………………………………………………………………………………………
d) …………………………………………………………………………………………………

viii) What advice do you give to other producers in order to have their biogas units run effeciently?

a) …………………………………………………………………………………………………
b) …………………………………………………………………………………………………
c) …………………………………………………………………………………………………
d) …………………………………………………………………………………………………

x) Do you ever get excess biogas from your biogas plant? *(1. Yes 2. No .)*

xi) If yes, what do you do with the excess biogas?

a) …………………………………………………………………………………………………

b) ……………………………………………………………………………………………
c) ……………………………………………………………………………………………

xii) What do you use the slurry from your biogas plant for?

a) ……………………………………………………………………………………………
b) ……………………………………………………………………………………………
c) ……………………………………………………………………………………………

xiii) State the major problems you experience with the slurry from your biogas plant.

a) ……………………………………………………………………………………………
b) ……………………………………………………………………………………………
c) ……………………………………………………………………………………………

xiv) How have you attempted to solve problems with the slurry from your biogas plant?

a) ……………………………………………………………………………………………
b) ……………………………………………………………………………………………
c) ……………………………………………………………………………………………

9. Outline the main routine operational & maintenance (O&M) activities you undertake in your biogas unit.

a) ……………………………………………………………………………………………
b) ……………………………………………………………………………………………
c) ……………………………………………………………………………………………
d) ……………………………………………………………………………………………
e) ……………………………………………………………………………………………

i) State five major operational & maintenance (O&M) problems you face in biogas production and utilization

a) ……………………………………………………………………………………………
b) ……………………………………………………………………………………………
c) ……………………………………………………………………………………………
d) ……………………………………………………………………………………………
e) ……………………………………………………………………………………………

ii) What form of labour do you use in your biogas unit? *(1.Family 2. Hired 3. Both)*

iii) If you use family labour, who of the family members actually attend(s) to the biogas unit most?

(1. Husband 2. Wife 3. children 4. other-specify …………………………………………)

iv) Who in the family is responsible for the overall management of the biogas unit?

(1. Husband 2. Wife 3. children 4. other-specify…………………………………………)

v) How many family members work in the biogas unit per day? *(…………………………)*

vi) For how long do the family members work in the biogas unit per day? *(………………. hours)*

vi) If you use hired labour, how many workers do you employ? *(.……………….workers)*

vii) For long do the labourer(s) work in the biogas unit per day? *(..………………… hours)*

viii) How much do you pay each labourer per *day/week/month*? *(...……………… shs)*

ix) Do you receive any external support for routine operational & maintenance (O&M) management of your biogas unit? *(1. Yes 2. No)*

x) If yes, from which source? *(1.Fellow biogas producers 2. Government extension workers 3. NGOs 4. Other- specify…………………………………………………….……… …)*

xi) What form of support do you receive? *(1. Financial 2. Material 3. Technical services 4. Other- specify……………………………………………….…….. ..)*

xii) Are you required to fulfill any conditions before you receive the support? *(1.Yes.. 2. No .)*

xiii) If yes, state the conditions that you must fulfill to get the support.

a) ……………………………………………………………………………………………

b) ……………………………………………………………………………………………

c) ……………………………………………………………………………………………

d) ……………………………………………………………………………………………

e) …………………………………………………………………………………………….

10. Have you ever received any formal training in biogas production and utilization? *(1.Yes 2.No)*

i) If yes, state the form of training received and who conducted it.

Training *Conducted by:*

a) ……………………………………………………………………………………………

b) ……………………………………………………………………………………………

c) ……………………………………………………………………………………………

d) ……………………………………………………………………………………………

e) …………………………………………………………………………………………….

ii) Do you easily get technical services for the biogas unit when required? *(1. Yes 2 . No)*

iii) If yes, who provides the technical services?

……

…………………………………………………………………………………………………

iii) Do you pay for the technical services? *(1. Yes 2 . No)*

iv) If yes, how much do you pay for the services? ……………………………………………….

11. Are you a member of any biogas production/utilization group(s) *(1. Yes 2 . No)*

i) If yes, name the group(s)

....……………………………………………………

……………………………………………………………………………………………..

ii) What benefits have you realized from the group(s) since you joined?

a) ……………………………………………………………………………………………

b) ……………………………………………………………………………………………

c) ……………………………………………………………………………………………

d) ……………………………………………………………………………………………

iii) What plans do you have for your biogas unit?

a) …………………………………………………………………………………………………

b) …………………………………………………………………………………………………

c) …………………………………………………………………………………………………

d) …………………………………………………………………………………………………

e) …………………………………………………………………………………………………

iv) In your view, how can biogas production and utilization be promoted in Uganda?

a) …………………………………………………………………………………………………

b) …………………………………………………………………………………………………

c) …………………………………………………………………………………………………

d) …………………………………………………………………………………………………

e) …………………………………………………………………………………………………

12. Estimation of other energy consumption levels:

i) Apart from biogas, what other form of energy do you use for cooking at home?

(1. Fuel wood 2. charcoal 3. kerosene 4. Liquefied Petroleum Gas (LPG)
5.electricity 6. Solar power 7. other- specify…………………………………..……….)

ii) Use the table below to indicate the cooking device and how much energy you use for cooking at home

Type of Cooking device used	Duration per day	No. of cooking devices used	Quantity of energy Used	Cost of energy
1. Fuel wood stove				
2. Charcoal stove				
3.Kerosene stove				
4.LPG stove				
5. electric stove				
6.Solar stove				
7. other:				
a)				
b)				
c)				
d)				
e)				

iii) What other form of energy do you use for lighting at home ? *(1. Fuelwood 2. charcoal 3. kerosene 4. Liquefied Petroleum Gas (LPG) 5.electricity 6. Solar power 7. Vehicle battery 8. Generator 9.other- specify………….. ……………………….)*

iv) Use the table below to indicate the lighting devices and how much energy you use at home:

Form of energy used	Type of lighting devices	No. of lighting devices	Duration for lighting per day	Quantity of energy Used	Cost of energy
Fuel wood					
charcoal					
Kerosene	Incandescent lamp				
	Lantern lamp				
LPG	LPG lamp				
Electricity	Florescent bulb				
	Florescent tube				
Solar power	Florescent bulb				
	Florescent tube				
Vehicle battery	Florescent bulb				
	Florescent tube				
Petrol /Diesel Generator	Florescent bulb				
	Florescent tube				
Other-Specify					
a)					
b)					
c)					
d)					
e)					
f)					
g)					

v) What other energy devices do you use at home ?

Type of device	No of devices	Type of energy used	Duration day	Quantity of energy Used	Cost of energy
Refrigerator					
Television					
Video deck					
Radio					
Air conditioning					
Fan					
Iron					
Water heater					
Washing machine					
Other-Specify					
a)					
b)					
c)					
d)					
e)					

vi).Show the proportion of biogas you use at home compared to other energy sources for the following end-uses:

End-use	Proportion of biogas energy used
Cooking	
Lighting	
Refrigeration	
Ironing	
Television	
Video deck	
Radio	
Air conditioning	
Washing	
Other-Specify	

vii) Do you use less or more biogas compared to other energy sources for cooking and lighting?

(1. less 2. more)

Give reasons for this current energy use status

a) ……………………………………………………………………………………………………

b) ……………………………………………………………………………………………………

c) ……………………………………………………………………………………………………

d) ……………………………………………………………………………………………………

viii) Do you prefer to use less or more biogas compared to other energy sources for cooking and lighting? *(1. less 2. more)*

Give reasons for this preference

a) ……………………………………………………………………………………………………

b) ……………………………………………………………………………………………………

c) ……………………………………………………………………………………………………

d) ……………………………………………………………………………………………………

ix) In future, do you plan to use less or more biogas? *(1. More 2. Less)*

Give reasons for the answer

a) ……………………………………………………………………………………………………

b) ……………………………………………………………………………………………………

c) ……………………………………………………………………………………………………

d) ……………………………………………………………………………………………………

e) ……………………………………………………………………………………………………

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

Biogas stove scoring

Criteria	**Fuel wood Stove**					**Charcoal stove**					**Kerosene Stove**					**LPG stove**					**Electric stove**				
Technical Evaluation																									
Fuel consumed	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cooking time	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Durability	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Reliability	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Sophistication	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Size/Space/ weight needs	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Ruggedness	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Seasonal/continuous use	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Nutritional level of food cooked	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Economic Evaluation																									
Initial cost	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Fuel cost	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Maintenance cost	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Interest rate on loan for device	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Subsidy availability	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Environmental Evaluation																									
Air pollution levels	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Deforestation potential	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Eutrophication potential	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Soil degradation levels	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Heavy metal pollution	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Commercial Evaluation																									
Improvement in models	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Availability of spares and after-sales service	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Distribution network	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Market research needs	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Need for training	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Social Evaluation																									
Human drudgery	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Overall safety in use	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Employment generation pote.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Gender sensitivity	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Behavioural Evaluation																									
Aesthetics	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Motivation to buy it	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Taste of food prepared	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cleanliness of utensils	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Ease of operation	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Exclusivity of types of dishes to be cooked on	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Need for extra cooking device/stove	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Thank you for sparing your valuable time to answer this questionnaire.