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Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications

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ABSTRACT

Dependence on fossil energy sources is increasingly becoming unsustainable due to ecological and environmental problems and rapid depletion. Biogas energy could augment these conventional energy sources but despite its advantages and favourable conditions for its production, biogas energy use in Uganda remains low due to technical, economic and socio-cultural impediments. Based on primary data on households in Central and Eastern Uganda and the use of logistic regression, this study analyses factors affecting the adoption of biogas energy in Uganda. The empirical results suggest that 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. Policy options and recommendations including educational and awareness campaigns on biogas benefits and successes, the provision of financial and non-financial incentives to households and establishment of an institutional framework could bolster wider biogas energy acceptance in Uganda.

1. Introduction

The role played by energy in society is overwhelming. Energy affects all aspects of development—social, economic and environmental (Amigun et al., 2008). Therefore provision of adequate, affordable, efficient and reliable energy services with minimum effect on the environment is crucial. Many countries depend on fossil fuels for their energy needs. However, this is increasingly becoming unsustainable because fossil fuels cause ecological and environmental problems (Karekezi, 2002) and are depleting rapidly. Problems associated with non-sustainable use of fossil fuels have led to increased awareness and widespread research into the accessibility of new and renewable energy resources (Amigun and von Blottnitz, 2007). This increased world-wide 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 region (Karekezi, 2002).

Biogas energy,[1] a clean and renewable form of energy, could augment conventional energy sources. Produced through anaerobic fermentation, biogas consists of between 40% and 70% methane, with the remainder being carbon dioxide, hydrogen sulphide and other trace gases (Singh and Sooch, 2004). Biogas energy has some advantages over other energy sources. Successful use of biogas technology can result not only in energy generation and bio-fertiliser production, but also other social and ecological benefits including sanitation, reforestation and reduction of imported fuel oil (Ji-Quin and Nyns, 1996). The technology has the potential to contribute to mitigation of greenhouse gas emissions (Han et al., 2008). Biogas systems lead to reduced eutrophication and air pollution and improved utilisation of crop nutrients (Lantz et al., 2007). By eliminating the daily task of firewood gathering, biogas technology reduces, if not eliminates, drudgery for women (Mwakaje, 2007). Further, biogas is produced mainly from raw materials that are locally available and can be harnessed in controllable, containable and useable quantities. In short, biogas energy production actually transforms a costly problem into a profitable solution.

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[1] We use the terms biogas energy, bioenergy and biogas technology synonymously throughout this paper.

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2. Overview of the energy sector and biogas energy 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, agricultural residues and kerosene for domestic use. Commercial energy comprises electricity and petroleum products, while alternative sources include renewable energy such as biogas and solar energy. The total annual energy consumption is estimated at 20 million tonnes of wood, 430,000 tonnes of oil products with a hydropower installed capacity of about 300 and 3 MW of thermal power (MEMD, 2002). Firewood is the most common cooking fuel, particularly in rural areas, and is used by 81.6% of households, while 15.4% use charcoal. 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 (MOFEPD, 2002). For high-income households, electricity is an option but for low-income households the high up-front costs render it inaccessible.

With this diverse endowment of energy sources, Uganda should not be experiencing the current acute energy supply shortages, particularly with per capita energy consumption among the lowest in the world. The shortages are further aggravated by the annual population growth rate of 3.7% and annual growth in demand for electricity of 7–8% (MEMD, 2004). This poses a huge challenge to the energy sector, indicating that supplementary energy sources have to be sought.

Biogas could reduce the widening energy sources gap for both cooking and lighting. The history of biogas technology in Uganda is relatively old, dating back to the 1950s. Current estimates based on livestock populations alone place the total theoretical biogas potential at about one billion m^3 per year, with energy potential equivalent to a 1000 MW hydropower plant and about 600 family-sized biogas digesters installed in the country (Pandey et al., 2007). Biogas energy has been popularised mainly by non-governmental organisations (NGOs) including Heifer Project International (HPI), Adventist Relief Agencies (ADRA), AMREF, Africa 2000 Network, among others.

The biogas plant designs used in Uganda are mainly the small-scale type commonly referred to as family-sized digesters with two basic designs: floating drum and fixed dome (Kandpal et al., 1991). The floating drum digester is not popular because it is very costly. An alternative inexpensive design within the reach of the rural poor – the fixed dome – has been invented with the basic principle of minimising the surface area of the equipment and reducing installation costs without compromising its functional efficiency (Singh and Sooch, 2004). 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 cost ranges between US$ 700 and 1200, depending on the size (Kassenga, 1997). A third digester, also referred to as the tubular, polythene or plastic digester, has recently been promoted to reduce installation and operation costs further by using local materials. The type of plastic needed for the polythene digester can be obtained locally and construction requires relatively simple skills, thereby significantly lowering costs. However, this type of digester is unpopular in Uganda because it has a much shorter lifespan than the other types.

Most family-sized digesters promoted in Uganda have installed biodigestion capacity volume of 8, 12 or 16 m^3. A few community and institutional biogas plants with capacity of 30 or 50 m^3 have also been installed. Cow dung is the sole feedstock for biogas digesters in spite of an abundance of other potential feedstocks, including agro-industrial wastes and residues, municipal solid wastes and waste waters, forestry by-products and residues, crop residues and household food wastes. Despite its advantages and relatively old history and the existence of favourable conditions for its production in terms of abundant biodegradable raw materials, warm tropical temperatures and availability of field-tested technologies, the development and adoption of biogas technology in Uganda has not been significant (Pandey et al., 2007). The potential of this appropriate technology has thus remained largely untapped. There is a need to understand the factors that could accelerate exploitation of the full potential of biogas energy in Uganda.

This study attempts to determine key factors influencing biogas utilisation decisions in Uganda. It is difficult to generalise about determinants affecting the adoption of technologies in different parts of the world due to differences in agro-ecological and socio-economic settings. For example, while the principal economic rationality assumption, the utility-maximising objective of individual households, might be the same for households everywhere, the specific attributes influencing the utility of households and adoption decisions are far from uniform (Bekele and Drake, 2003). Therefore, an understanding of the socio-economic factors influencing biogas utilisation in Uganda would assist in policy formulation and implementation of programmes designed to promote voluntary adoption of the technology by households.

3. Methodology

This study was based on a survey conducted between November 2007 and April 2008 in the districts of Luwero, Nakaseke and Nakasongola in Central Uganda and Mbale, Sironko and Manafwa in Eastern Uganda. These districts were selected because they have 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 this region than in other parts of the country.

Prior to the formal survey, a baseline survey was conducted using individual interviews and focus group discussions with households and key informants. The information collected in the survey helped to guide the development of formal questionnaire and interview schedules. Both primary and secondary data were collected using a self-administered questionnaire and personal interviews. Primary data were collected from 220 households categorised as ‘biogas producers and users’ and ‘non-producers and non-users’, hereafter referred to as ‘biogas users’ and ‘non-users’, respectively. Given the limited number of biogas users, 100 households within that category were actively selected depending on their willingness to participate in the interviews, while 150 non-users were randomly selected and interviewed. For each biogas user, at least one non-user was chosen at random. The sampling method could not be based entirely on a random selection because the number of biogas users in relation to the total number of households in the study area was too small, which made it difficult to obtain a satisfactory number of observations from a totally random selection, and because no complete list of biogas users was available from which a sample could be drawn. After thorough inspection of the completed questionnaires, a final sample of 84 biogas users and 136 non-users formed the basis for our analysis.

The data collected included socio-economic and demographic characteristics of households, which could be broadly grouped into physical, socio-economic and institutional aspects. Data were analysed using statistical techniques (principally descriptive statistics, cross tabulations, frequency tables and logistic regression) with the aid of the Statistical Package for Social Scientists (SPSSv12) software.

Supplementary data (mainly secondary) were obtained from other key stakeholders in the biogas industry in Uganda including the Ministry of Finance, Planning and Economic Development (MOFEPD), Ministry of Energy and Mineral Development (MEMD), Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), academic institutions, NGOs actively involved in the promotion of biogas energy, biogas technicians and equipment manufacturers and the private sector dealing in biogas spare parts and accessories.

4. Conceptual framework and modelling adoption of biogas technology

4.1. Conceptual framework

The basic economic principle underlying this study stems from economic theory that attempts to estimate the economic value individuals place on various goods and/or services. Consumers have subjective preferences for characteristics of products and their demand for products is significantly affected by their perceptions of product attributes (Adesina and Baidu-Forson, 1995). Households rank acquisition of technology indirectly through the characteristics various items possess and a given technology embodies characteristics that influence adoption decisions (Somda et al., 2002). The observed adoption choice of a technology is the result of a complex set of interactions between comparable technologies and the user's socio-economic and demographic characteristics.

The key assumption is that households know their major energy problems and can state their preference among the available alternative technologies for addressing these, given their resource envelope and a vector of other observable attributes. The adoption of a new technology can therefore be modelled as a choice between two alternatives; the traditional technology and the improved technology (Fleke and Zegeye, 2006). Observations of a household's preferences among the different energy technology options available can reveal that household's ranking of the options.

Following Dorfan (1996), we assumed that the household derives utility from choosing a particular option given its resource endowment and observable attributes. The choice of this particular option can be represented by k, where $k=1$ if the household is willing to choose a given technology and $k=0$ otherwise. Resource endowment is represented by r, and the vector z represents other observable attributes of the household that might potentially affect the desirability of the technology being proposed. If the household prefers the proposed technology, its utility is given by

$$U_1 = U(1, r, z),$$

or if it does not prefer the proposed technology

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

A utility-maximising household will adopt an improved technology only if the random utility of the technology $U_1 > U_0$. As it is common in the specification of utility functions, we assumed a cumulatively distinguishable utility function in the deterministic and stochastic components where the deterministic component is assumed to be linear in the explanatory variables such that:

$$U_1 = U(1, r; z) = T(1, r; z) + \varepsilon_1 \quad (3.1)$$

and

$$U_0 = U(0, r; z) = T(0, r; z) + \varepsilon_0 \quad (3.2)$$

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

$$U_1(\cdot) \geqslant U_0(\cdot),$$

$$T(1, r-C; z) + \varepsilon_1 \geqslant T(0, r; z) + \varepsilon_0. \quad (3.3)$$

The presence of the random component allows us to make probabilistic statements about a decision-maker's behaviour. The disturbance terms are assumed to be independently and identically distributed. If the household prefers the technology being proposed, the probability distribution is given by

$$P_1 = \Pr(Yes) = \Pr(T(1, r-C; z) + \varepsilon_1 \geqslant T(0, r; z) + \varepsilon_0, \quad (3.4)$$

and if the household does not prefer the technology

$$P_0 = \Pr(no) = \Pr(T(0, r; z)) + \varepsilon_0 \geqslant \Pr(T(1, r-C; z)) + \varepsilon_1. \quad (3.5)$$

With the assumption that the deterministic component of the utility function is linear in the explanatory variables, the utility function in (3.1) and (3.2) 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 Eqs. (3.4) and (3.5) can be given as

$$\begin{aligned} P_1 &= \Pr(Yes) = \Pr(U_1(\cdot) \geqslant U_0(\cdot)) \\ &= U = \beta_1 X_i + \varepsilon_1 \geqslant \beta_0 X_i + \varepsilon_0 \\ &= \Pr(\beta'_1 X_i - \beta'_0 X_i \geqslant \varepsilon_0 - \varepsilon_1. \end{aligned} \quad (3.6)$$

When each technology is thought of as a possible adoption decision by the household, the household can be expected to choose the technology that has higher expected utility among the alternatives considered (Bekele and Drake, 2003).

4.2. Empirical model

The logistic model was used to investigate the biogas technology adoption process. Both probit and logit analyses are well-established approaches in adoption studies (Burton et al., 1999). The choice of whether to use a probit or logit model 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). 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

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

$$P = \frac{e^{a+bX}}{1+e^{a+bX}} \quad (4.1)$$

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:

$$\Pr Y = \frac{1}{1 + e^{-(a+bX)}}, \tag{4.2}$$

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

$$\begin{aligned} Y &= \ln(\text{odds(event)}) = \ln(\text{prob(event)}/\text{prob(nonevent)}) \\ &= \ln(\text{prob(event)}/[1 - \text{prob(event)}]) \\ &= b_0 + b_1X_1 + b_2X_2 + \cdots + b_nX_n, \end{aligned} \tag{4.3}$$

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).

4.3. *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 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.

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. They 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).

Table 1
Definition of explanatory variables for biogas energy adoption model 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 (USh).
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[a]; (1 = <500,000; 2 = 500,000–1,000,000; 3 = >1,000,000)

[a] Exchange rate 1 USD = USh 1700.

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,

Table 2
Explanatory variables with *a priori* signs for biogas energy adoption model 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	+

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

5. Results and discussion

5.1. Profiles of biogas 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 3. 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 3). 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 (Table 3).

5.2. Factors influencing biogas energy adoption 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 4), 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 3
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*
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 (%)			
$<$USh 500,000	82.1	83.8	83.2
USh 500,000–1,000,000	16.7	14.7	15.5
$>$USh 1,000,000	1.2	1.5	1.4

* 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).

Table 4
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 $\chi^2 = 3.110$ ($P>0.05$).
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).

(Table 4). This indicates that the model fitted the data to an acceptable level.

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 4). 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's 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 nine 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 4). 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 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 4). 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 4). 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 4). 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.

6. Policy implications and recommendations

This study showed that socio-economic and demographic characteristics of households are important determinants of biogas adoption behaviour. Some proactive policy issues could be drawn from these results when designing programmes for promoting biogas energy. First, the negative correlation of age of household head with the adoption of biogas technology is crucial regarding the categories of households to be targeted. Those involved in technology development and dissemination have long believed that new technologies should be targeted at mature heads of household, mostly over 50 years old (Somda et al., 2002). Thus the focus is more on those who it is hoped will adopt the technologies than those who actually will do the adopting (Koppel, 1985). Our results suggest that the younger generation is central in the biogas technology transfer process and therefore the earlier they are involved in biogas planning and development, the faster and better could be the outcome of this process.

Gender relationships regarding male–female asset ownership and control vis-à-vis their vital role in agricultural activities in rural areas and how this could impact on key decisions regarding the uptake of biogas energy need to be considered. While men are usually the final decision-makers on whether to set up a biogas unit, women and children are more involved in the actual routine operation and maintenance of the unit. The results from this study suggest that households headed by women are not differently constrained from adoption of biogas technology. Targeting modern energy technology projects at women in rural areas would ease the daily labour burden placed on them (Karekezi and Kithyoma, 2002). Any time-saving modern energy such as biogas could go a long way in enhancing the productivity of women in agricultural activities. Promotion of biogas technology in this regard could achieve multiple benefits from the gender point of view. It could lead to increased food security through use of slurry – a high-value fertiliser – and improved nutritional status of the household by encouraging livestock farming (major source of feedstock but could also provide milk).

The siting 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, particularly since some studies stress that whether at the local, regional or community level, selection of the right location for biogas development is very important (Ji-Quin and Nyns, 1996). Whether in an urban or rural area, the family biogas digester would be more acceptable if it were financially profitable compared with other productive activities. The digester system should therefore be made more economically attractive through the integrated use of biogas technology whereby households are encouraged to use residues from the biogas system as a crop fertiliser in order to increase economic benefits and competitiveness.

Considering the long-term benefits of the technology both economically and environmentally, 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 adopter in order to share the economic burden of the investment with the household. This has been practised in many developing regions, especially at the initial stage of biogas implementation (Gupta and Ravindranath, 1996; Ji-Quin and Nyns, 1996; Adeoti et al., 2000; Singh and Sooch, 2004). In Uganda, 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. However, policy-makers and all the institutions involved must exercise great caution by recognising that borrowers are not homogeneous and that the marginal productivity of credit would be different among the different borrowers. They should therefore give first priority to those in greatest need of additional capital in order to obtain the greatest impact from the credit.

The socio-cultural constrictions could be overcome through intensive education campaigns to raise awareness of the benefits of this technology. These could include publication and distribution of simple and well-illustrated manuals, various propaganda mechanisms, especially to rural areas through the mass media, organisation of training courses and seminars (Akinbami et al., 2001). There is need to highlight biogas success stories in Uganda and encourage dissemination of information through exchange visits and personal testimonies. The most important element of this promotion strategy would be to have a satisfied customer telling friends, visitors, relatives and neighbours about the benefits of a biogas digester. However, it is important to accurately inform potential customers of the specific requirements of a digester without exaggerating its benefits.

The institutional framework for the popularisation and coordination of biogas technology in Uganda is weak. 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 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 (Karekezi and Kithyoma, 2002). This creates an ownership gap for the installed systems, since households only pay a minimal installation fee and view the biogas systems as externally owned, requiring continuous support to maintain them. Consequently, the systems break down completely or are abandoned altogether. An umbrella body, for instance the National Integrated Biogas Development Programme, could be set up with the main task of coordinating and stimulating interaction between farmers, researchers, biogas companies (suppliers), biogas plant operators and the public through a bottom-up approach. This would create a broad social network for the stakeholders and stimulate the exchange of experiences between biogas users and other social groups.

7. Conclusions

Biogas technology offers a good potential energy option for Uganda through its various advantages. However, the adoption and success of biogas technology remain very low. Factors identified as positively promoting the development of biogas in Uganda included younger/male head of household, increased farm income or number of cattle owned, larger household size and increasing cost of traditional fuels. Factors with a negative impact on biogas adoption included household location and farm size. Policy options that could greatly increase the adoption and continued success of biogas technology in Uganda have been highlighted.

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