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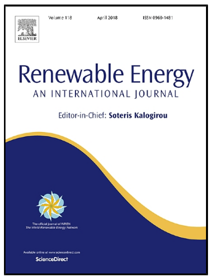

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Economic potential of flexible balloon biogas digester among smallholder farmers: a case study from Uganda

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Abstract

Biogas technology, as a pro-poor renewable energy source, has been promoted in Uganda since the 1980s by the government and NGOs. However, many of the biogas designs promoted have proved to be too expensive for the average Ugandan to afford. A cheaper flexible balloon digester has been proposed, but there have been lack of evidence on the economic viability of this design. The purpose of this study was to analyze the economic potential of a flexible balloon digester among smallholder farmers in Uganda using the tool of cost-benefit analysis. Primary data were obtained from survey of experimental households and 144 non-biogas households in central Uganda. The results revealed that the net present value was negative and the payback period was greater than the economic life of the digester. However, sensitivity analysis revealed that with a 50% reduction in investment cost the technology is financially viable for 67% of the households and to all households as a group (NPV= UGX5,804,730). The initial investment cost is a critical factor to viability and potential adoption. We suggest that government and development partners interested in the sector should consider strategies that could reduce strategies that could reduce the technology cost e.g., manufacturing low cost balloon digester locally.

Keywords
Biogas, cost-benefit analysis, economic viability, flexible balloon digester, Uganda

1. Introduction

Biogas[1] has a long history, but it was not until the two oil shocks of 1973 and 1979 that energy production from renewable sources including biogas was considered as an element of energy policy (OECD, 1984). During the period between 1972 and 1982, international oil prices increased fivefold and then dropped steadily so that by 1987 they were roughly at the same level as in 1972. In Uganda, biogas production dates back to the 1950s, and there have been growing attempts since 1985 to promote biogas energy technology by government, private initiatives and non-governmental organizations (NGOs). The NGOs that have spearheaded the promotion of biogas energy production include Heifer Project International (HPI), Adventist Relief Agencies (ADRA), African Medical and Research Foundation (AMREF) and Africa 2000 Network (Walekhwa, 2010). The NGOs' initiatives have demonstrated the benefits of biogas production by installing the biogas digesters across Uganda.

A study by Walekhwa et al. (2009) indicated that Uganda has a potential to generate 1740 Mtoe of energy from animal waste at a recoverable rate of 30%. If this energy is fully utilized, the health, economic and environmental outcomes of households would improve (Peipert et al., 2008). However, most efforts aimed at promoting biogas in Uganda have mainly focused on feasibility of the biogas production from two digester designs i.e., the fixed-dome and floating drum digesters (Walekhwa et al., 2009; Winrock International, 2007). However, these digester designs have proved to be too expensive for the average Ugandan to afford (Winrock International, 2007). Walekhwa (2010) reported that the total cost for the fixed doom plant range between UGX 6 - 20 million (ca. USD 2000-7000), depending on the size of the plant. This is beyond the reach of most households in a country where the national level per capita income is just about USD 770 (World Bank, 2014).

However, the economics and local preferences of alternative cost-effective designs of biogas digesters[2] such as flexible balloon designs have not been fully investigated in Uganda. There has been only limited research in the economics of the flexible balloon digesters, especially on how the installation and maintenance costs of this cheaper biogas technology compare with the monetary savings made by households changing from fuelwood to biogas for domestic energy demand.

The purpose of this study thus was to assess the economic feasibility of a cheaper biogas digester design, known as 'flexible balloon' design among smallholder farmers using a case study from Uganda. Detailed empirical data on a range of cost and benefit items associated to the 'flexible balloon' biogas digester design have come from an experimental/pilot household records

[1]Biogas technology is an integrated waste management and clean and renewable energy production system. Biogas is produced through an anaerobic biological process using any available organic material such as cow dung, human excreta, and food wastes. The gas produced is similar to natural gas and is composed of 50-70% methane, the remainder being composed of carbon dioxide and traces of hydrogen sulfide and ammonia. It can be used mainly for heating, cooking, and electricity production.

[2] See appendix A for brief descriptions of the three most common biogas digester designs in use in Sub-Sharan Africa.

established in Tiribogo community in central Uganda. As part of the Department for International Development of the United Kingdom (DFID) funded '*New and Emerging Technologies Research Competition (DFID NET-RC)*' grant in Africa, a total of nine flexible balloon digesters were installed in 2013 in nine smallholder farm households in Tiribogo village in central Uganda. The biogas digesters with 8 m^3 volume and made from more robust 850 g m^{-2} grade plastic was used in the study. The digesters were installed of the plug-flow type. This consist of a bag with an elongated shape, with a length to width ratio of about 5:1. The wet organic waste is fed into one end of the digester and the effluent material comes out of the other end. The bag (digester) is mounted in a shallow ditch which supports the digester (bag) with the feedstock contained within it. The biogas produced bubbles out of the decomposing organic waste and is stored in the upper part of the bag. The gas is piped from the bag through a gas connection on top, and from there it is piped into the kitchen. In its least complex form, there are no systems for stirring or heating up the contents of the digester.

These digesters were monitored for about a year and detailed empirical records on the socio-economics, technical, and operational aspects of the installed digesters were obtained. The aim was to obtain empirical data that would help assess the technical (e.g., quantity of gas), social (e.g., household health impact) and economic (i.e., the costs and benefits) of alternative biogas design in Uganda in particular and establish decision support evidence for the potential of cost-effective biogas digesters design in Sub-Saharan Africa. It focused on cheaper designs of digesters to encourage wider uptake of biogas technology amongst the poor members of the community and to provide a long-term energy supply.

This paper focuses on addressing two key questions related to the economic aspect of the flexible balloon design: (i) How do the economic cost of acquiring the technology including maintenance and operational costs compare to the costs saved and additional benefits accrued in using the flexible balloon digester? (ii) Do smallholder farm households better off by changing their domestic energy use from fuelwood to biogas? In order to address these questions, we applied a cost-benefit analysis.

2. A brief overview of cost-benefit analysis

CBA is an applied economic tool often used to guide the allocation of resource or investment decisions or policy alternatives or decisions involving the management of natural resources (OECD, 2006; Park and Oxon, 2012). It is a technique that is used to estimate and sum up (in present terms) of the future flows of benefits and costs of resource allocation decisions or policy alternatives to establish the worthiness of undertaking the stipulated alternative and inform the economic efficiency to the decision maker. The basic rationale for CBA is rooted in the 'principle of potential compensation' (Hicks, 1939; Kaldor, 1939). This principle states that an action is more efficient if those that are made better off could potentially compensate those that are made worse off. In situations where benefits and costs of an action are spread over time, decisions are based on comparing the present value of benefits and costs. With regard to decisions related to technology adoption, the role of CBA is to measure the benefits and costs of technology adoption and consequently enables the comparison of the two systems – that with the proposed change and that of without it. The with-and-without approach is at the heart of the cost-benefit process.

CBA has been applied in the economic assessment of investment in various environmental and renewable energy technologies including biogas digesters. Kandpal et al (1991) used the CBA framework to analyze the economics of family-sized floating dome biogas digesters in India. Gwavuya et al (2012) and Walekhwa et al (2014) have applied the CBA tool to assess the economic potential of biogas technology as an alternative source of household energy in Ethiopia and Uganda respectively. Using a case study in Valmiera city in Latvia, Dobraja et al (2016) applied CBA to evaluate the economic value of environmental aspects of waste-to-energy process to guide prioritization of investment options. Zhang and Chen (2016) used a modified version of the traditional CBA and applied emergy-based CBA to conduct a comprehensive assessment of the economic and ecological performance of urban biogas project. Wresta et al (2015) implemented the tool of CBA in the economic analysis of cow manure biogas as energy source in small scale ranch. Most recently, Abbas et al (2017) employed a benefit-cost ratio decision criteria to estimate the financial benefits of adoption of biogas technology by rural farmers in Pakistan.

However, applying CBA in adoption decision, particularly on environmental decisions involve various challenges. One major challenge arises from the fact that many environmental goods and services are not traded directly in market transactions. Hence, attaching monetary values to them becomes a difficult task (OECD, 2006). Despite remarkable developments in non-market valuation methods, attaching accurate values to a large number of environmental goods and services remains a big challenge. Another major controversy in applying CBA is the choice of the discount rate for converting future flows of benefits and costs into current terms (called 'discounting'). From an economic point of view the discount rate should reflect the decision maker's time preference. In public projects, choosing a relevant time horizon from the perspective of various stakeholders is another important consideration in CBA application. Despite the challenges, CBA remains an important analytical tool in environmental decision making.

This study applied the CBA using empirical data on costs and benefits obtained from the experimental households in Tiribogo community (south-west Uganda) and questionnaire survey of sampled households in the vicinity of the experimental community in Mpigi district (Uganda). The method of estimating the cost and benefit items are detailed in section 3.3.

3. Materials and Methods

3.1 Description of the Study Area

The study was conducted in Mpigi district, Muduuma Sub-county in Tiribogo community (Figure 1). Muduuma Sub-county is located on 0°21'5" N and 32°17'56" E and has average minimum and maximum temperature of 15 ^{o}C and 28 ^{o}C respectively. The areas experience a bi-modal rainfall pattern, with the first season starting in March-April and ending in May. The second rain starts in July and go up to November and are usually more reliable. The annual rainfall ranges from 800mm and 1200mm. Tiribogo village is bordered by Muduuma forest reserve with dominant vegetation consisting of savannah woodland. The Village has a total population of 4,800 whose main livelihood is agriculture.

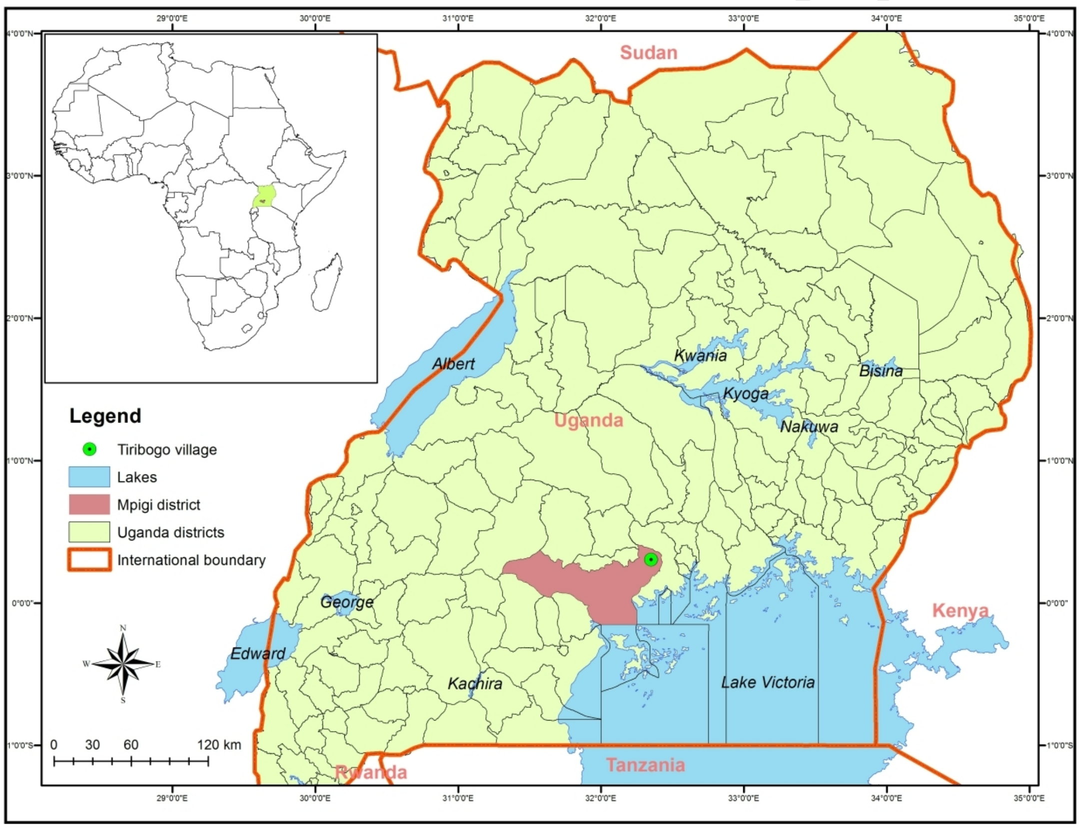

Figure 1. Map showing the study area

Agriculture in the area is characterized by subsistence mixed crop-livestock farming, with farmers rearing animals and growing both food and cash crops. The food crops mainly grown in the Mpigi district where Tiribogo community is located and the respective quantities produced as per the Uganda Agricultural Census 2008/2009 include banana (87,658 megatons (Mt)), sweet potatoes (21,478 Mt), maize (19,578 Mt), beans (7,212 Mt) and horticultural crops such as cabbages and indigenous vegetables e.g., nakati (*Solanum aethiopicum*) and amaranthus

(*Amaranthus caudatus*) while coffee (15,000 Mt) is the main cash crop grown. The animals reared and their respective population include pigs (108,082), goats (102,828) and cattle (216,621), and these were reared on small scale with most households keeping at least one of these animals. Tiribogo village has no grid connection and the main source of energy used for lighting is kerosene. Most of the household use fuelwood as their main source of energy for cooking, although some of the households use charcoal for cooking. Fuel wood and charcoal are the main source of energy for cooking because the village is bordered by the forest where trees are cut and used for fuelwood and charcoal. Institutions like schools consume a lot of fuelwood energy for preparing students meals.

The area was purposely selected because it is where the flexible balloon digesters were being experimented under DFID funded NET-RC project. The project provided flexible balloon digesters to nine selected households in Tiribogo village to test and document the technical, social, and economic performance of an alternative cheaper biogas digester design which would help provide decision support evidence for adoption and long term supply of energy to the community.

3.2 Sampling and field data collection

The data used in this study have come from the survey of Tiribogo community in central Uganda where the flexible balloon digesters was being experimented. This area was identified with the highest concentration of households with livestock that was to provide feedstock for the biogas digesters. The initial ground work began with identifying the nine households that would be given the nine flexible balloon digesters. To identify pilot households, all the 54 households in the community that produce animal manure were visited and interviewed for about 30-minutes each using a structured questionnaire, consisting of a list of closed questions on how the household manages its resources, such as farm, manure, water, fuel wood and kitchen residues. The data collected was used to generate fact sheets and to rank the suitability of households for installation of a flexible balloon biogas digester. A weighted multi criteria approach consisting of four factors – availability of feedstock, access to water, household's current fuelwood consumption and household labour availability – were used to identify pilot households.

Once the pilot households identified, farm household data were collected in two different timelines: (i) Baseline survey (before digester installation): a baseline survey was conducted in July 2013 to determine the situation before the digesters were installed with the nine households selected. The sampling frame for the baseline survey included the nine experimental households and 144 randomly selected other households that were within a close proximity of each of the nine households i.e., 16 randomly selected households to each pilot household based on community's local council register. A face-to-face structured questionnaire interview was administered by the first author (as part his graduate study research) and supervised by his advisors. (ii) The second round follow-up survey was conducted six months after the installation of biogas digesters. This was to give time for the pilot households to undergo a change in living as a result of using biogas. The follow-up survey on the nine pilot households was focused on the use of biogas energy, feedstock supply, changes in the household's labour demand and other resources. All the 144 'non-biogas' households included in the baseline were also interviewed in the follow-up survey to understand neighborhood effects and the likelihood of technology adoption.

3.3 Estimation of the cost and benefit items

The major cost components of the flexible balloon digester include the investment cost incurred to acquire the digester and operational and maintenance costs. The key part of operational cost is household labour time on various activities such as water collection, collecting substrate, mixing feedstock and feeding the digester. The operational costs were obtained by asking the farmers with digesters how much time they spent on carrying out these activities each time they fed the digester.

The benefits gained include biogas for cooking and lighting, use of slurry as a fertilizer, improvement in health and hygiene, and sale of the biogas produced by the household (if they manage to produce biogas more than the household demand). Biogas benefits in the form of 'reduced costs' due to the substitution of biogas to fuelwood and kerosene are the most important benefit items. The reduced costs comprises of the reduction in labour for fuelwood collection and the cost of kerosene saved. There exists rural labor market in Tiribogo area partly due to the proximity of the area to nearby population centres. The local rural wage daily rate of 5000 Ugandan shillings (UGX[3]) for unskilled workers was used to convert labour time into monetary value estimates.

In order to determine the value of the reduced labour cost for fuelwood collection or expenditure on fuelwood, households were asked the frequency of fuelwood collection each month or the amount they spend if they would buy fuelwood before and after they installed the digester. These information were captured in the baseline as well as follow-up surveys. The time saved from fuelwood collection was determined as the difference between the time spent for fuelwood collection before and after the installation of the digester.

Reduced costs on kerosene are costs that would no longer be spent on buying kerosene if light is provided by biogas. Savings made from replacing kerosene for lighting with biogas were determined as the difference between the amount spent on kerosene before installation and after installation of the digesters.

[3]This wage rate is for 6 hours of effective work time. 1USD is about 2600 UGX during the survey time.

The amount of biogas generated per year in mega joules by each household was recorded and estimated during the study (Appendix B). To estimate the value, the mega joules were converted to electricity equivalent using a conversion factor (one Kilowatt hour of electricity is equivalent to 3.6 mega joules). In Uganda, the price of 1 Kilowatt of electricity in 2013 was 500 Uganda shillings (UGX[3]). The number of kilowatts were multiplied by the unit cost of the Kilowatt. The data from the experimental households were collected for six months but the results were converted into annual equivalent. Some of the benefits from adoption of biogas technology such as the positive health impacts and clean household environment do not have market values. For such non-marketed benefit and cost items we used data generated through a contingent valuation method (non-market valuation approach)[4] (Singh and Sooch, 2004; Sabah and Jeanty, 2011; GIZ, 2010) conducted in the study area.

On the other hand flexible balloon digesters have certain technical difficulties which may undermine adoption of these technologies. The plastic tube is vulnerable to damage if not adequately protected from animals and other potential hazards. It can be easily damaged by animals, humans (children), sharp objects, etc. It can be also degraded by prolonged exposure to Ultraviolent (UV) light. Flexible tube digesters have a constant volume, which means that the biogas produced has a variable pressure, depending on the volume of gas in the digester. After prolonged periods of cooking, the gas pressure can drop. The gas pressure and activity of the micro-organisms decomposing the organic waste are also more affected by changes ambient temperatures than in designs with better insulation, such as fixed dome digesters that are constructed underground. The pipe that transports the gas from the digester to the kitchen can bend, leading to possible blockage of the gas line.

3.4 Analytical approach

The net present value (NPV) and payback period (PBP) criteria were used to evaluate the financial viability of household's investment in a flexible balloon digester. NPV is defined as the difference between the sum total of the present value of benefit streams and that of cost streams (including the initial investment cost) over the life of the project. Equation (1) presents the mathematical expression of the NPV computation (GIZ, 2010; Walekhwa et al., 2009). The future sum of money is discounted back to present to find the present value of the expected future sum. In this study, 11.5% discount rate was chosen based on the interest rate charged by Bank of Uganda in disbursing loans to banks in the survey (2013). The study assumed 5 years of useful economic life for a flexible balloon digester when adequately maintained.

[4] As part of the project, a parallel survey on the valuation of biogas technology using a stated preference method (contingent valuation) was conducted in the study area.

$$NPV = -INV + \sum_{k=1}^{n} \frac{CF_k}{(1+d)^k} -------------------- (1)$$

where *INV* is the initial investment for the flexible balloon digester (UGX) and CF_k is the annual net saving in the k^{th} year (UGX) and d is the discount rate (%). Under the *NPV* criterion, investments with positive *NPV* are considered to be economically feasible. This implies that the rate of return on the investment is higher than the discount rate used and is greater than the opportunity cost of capital used to finance the investment. Projects with a negative NPV should be rejected while a zero NPV makes the investor indifferent, in which case other factors and benefits relating the investment should be considered (Walekhwa, 2010).

The PBP refers to the number of years it would take for an investment to return the original cost of the investment through the annual net cash revenue it generates. The net saving provides a basis from which payback period can be calculated. Assuming a constant net annual saving or cash flow (CF) from the digester (Singh and Sooch, 2004), the PBP can be calculated the project can be obtained by dividing the initial investment cost (IC) by the net annual savings (equ.2):

$$PBP = IC / CF -------------------------- (2)$$

4. Results and discussion

4.1 Results from the survey of experimental households

The majority of the households (90% and 89%) use fuelwood for cooking and kerosene for lighting respectively. Fuelwood is affordable and fairly available from the surrounding forest. Fuelwood is often perceived as the cheapest form of energy available to low income households (da Silva and Sendegeya, 2006). Similarly use of kerosene for lighting is attributed to limited access to electricity. The findings are consistent with the statistics reported by MFPED (2002) where over 80% of households in Uganda use kerosene for lighting. The majority (85%) of the households reported that they get their fuelwood from the natural forest. This is because the households are in close proximity to the forest and so could easily access to fuelwood. Similar to this finding, Shrestha (2010) in a study on the prospects of biogas in terms of socio-economic and environmental benefits to rural community of Nepal, found that the local people in the study area depended on the forest resources as the main source of fuelwood.

The findings furthermore reveal that households reported were willing to pay UGX 135,000 (just over USD 50 per digester) to purchase a new flexible balloon digester. Considering the actual cost of a flexible balloon digester (UGX 1,332,630), ca. USD 500, it portrays that the amount households were willing to pay for a new digester is 10 times less than the actual cost of the digester. The high actual cost is attributed to importation and the low willingness to pay can be explained by the low household income.

Table 1 indicates that cooking with biogas takes more time than using fuelwood for all meals except breakfast though the latter is not statistically significant. The results show that cooking using fuelwood takes shorter time than that of biogas. The intensity of the flame obtained with fuelwood can be increased to produce hotter flame by feeding the fire, whereas the intensity of flame produced by biogas cannot be increased to suit for a bigger cooking utensils coupled with small cooking stove. The calorific value of $1m^3$ of biogas is 20 MJ and its burning efficiency is 34% (Gwavuya et al. 2012) but gas production from the plastic digester can be affected by unfavorable weather condition (Agrahari and Tiwari, 2013) whereas 1 kg of firewood has an average calorific value of 18 MJ and a use efficiency of about 10% (Gwavuya et al. 2012). This means that provided fuelwood is dry, addition of more fuelwood to the stove will likely increase the calorific value which makes cooking faster. With regard to cooking breakfast, surveyed households claim that school children and household members working off-farm leave the house early in the morning and they are not served with freshly cooked breakfast. So, cooking breakfast for the remaining few members of the household using a small saucepan well suited to the small cooking stoves with biogas energy takes a shorter cooking time than that of fuelwood (Table 1).

Table 1: Analysis of variance (ANOVA) of cooking time for various meals using biogas and fuelwood

	Fuelwood		Biogas		Mean sum of square		Test		
Meal	Average time taken in minutes per day	Std.	Average time taken in minutes per day	Std.	Between group	Within group	F-observed	p-value	F-critical
Breakfast	24	12.2	30	2.6	168.1	82.8	2.029	0.174	4.494
Lunch	114	4.0	120	2.6	168.1	11.3	14.865	0.001	4.494
Dinner	124	1.4	118	3.9	168.1	8.6	19.643	0.000	4.494
Supper	108	11.6	120	2.6	648.0	71.0	9.127	0.008	4.494

Source: Survey data, 2013; Std= standard deviation

The finding in this study (in relation to cooking time) is in contrast to the findings in a number of studies. For instance, the study by SNV (2009) in Bangladesh reported that 48.6 minutes were saved every day by converting to biogas (SNV, 2009). Similarly, Walekhwa (2010), Agrahari and Tiwari (2013), and Garfi et al., (2011) have shown that cooking using biogas takes shorter time than cooking using fuelwood. Moreover a study in the Peruvian Andes involving 12 rural families in a project to substitute biogas for firewood, showed a decrease of firewood consumption by 50%–60% and cooking time by 1 hour (Garfi et al., 2011). The likely reason for the divergence is attributed to the digester design and the small size of cook stove used in this study area which may necessitate cooking more than once in some households to serve a meal for a large household size**.** Fact Foundation (2012) reported that when selecting a stove, it is important to determine the required power and small stove size could increase cooking time in comparison to the traditional way of cooking.

In designing a low cost biogas pressurizing system, similar to the one used in this study but with slight modification, Geiger and Regan (2014) conducted an experiment to test the time taken while cooking 0.45 kg of dry beans using the wood burning stove and the biogas digester in Nicaragua. The results revealed that it took 120 and 105 minutes to cook 0.45 kg of dry beans using the wood burning stove and biogas digester respectively. The time taken in cooking lunch and supper using fuelwood in this study is slightly lower than that of the study conducted by Geiger and Regan (2014), by 6 and 12 minutes respectively (Table 1). Whereas cooking using biogas in Geiger and Regan (2014) experimental test takes a shorter time than in this study, because the digester in their experiment was designed to regulate and avoid gas losses and thus more gas was available and this took less time to cook. Another reason for the discrepancy could be the inefficiencies of a plastic digester such as failure to maintain gas for a long period. For instance, Njoroge (2002) observed that with a tubular plastic digester, there could be problems in maintaining high gas pressure for the extended period of time needed to cook a typical meal, suggesting that cooking food using biogas from a tubular plastic digester is likely to take a longer time than using other biogas digester designs. Agrahari and Tiwari (2013) also reported that fluctuations in gas production, especially in the morning and late evenings, are very inconvenient and result in a longer cooking hours. The issue of low gas production in the morning and evening is based on how well the digester is insulated from weather elements, such as sun, rain, and wind.

Table 2 shows the costs and net savings by an individual household substituting biogas energy from flexible balloon digester for both fuelwood (cooking energy) and kerosene (lighting). All the nine households using the biogas had a positive net annual savings as a result of substituting biogas for fuelwood and kerosene.

Table 2: Costs and savings associated with substituting biogas energy for fuelwood and kerosene

	Experimental Household No.								
	HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8	HH9
Initial investment (in '000 Uganda shillings)	1,333	1,333	1,333	1,333	1,333	1,333	1,333	1,333	1,333
Costs associated with biogas digester operation (in '000 Uganda shillings) per year									
Collecting water	12	36	54	25	12	8	42	67	18
Collecting substrate	20	24	24	14	16	30	24	56	12
Mixing of feedstock	30	18	24	14	12	20	48	28	6
Feeding the digester	12	18	12	14	8	10	12	42	12
Total cost (A)	74	96	114	67	48	68	126	193	48
Amount spent/saved (in '000 Uganda shillings) per year									
Savings from fuelwood	120	296	268	272	284	208	228	320	212
Savings from kerosene	50	25	18	23	20	90	29	96	48
Total saving (B)	170	321	286	295	304	298	257	416	260
Annual net savings ('000 UGX) (B-A)	96	225	172	228	256	230	131	223	212

Source: Survey data, 2013
Exchange rate during the survey period: 1US $ = 2600 UGX

Collecting water and feeding the substrates to the digester are the two major labour demanding activities. If water source or collection point is in close proximity to the household, the household incurs low operational cost. The low biogas cost of HH5 and HH9 (Table 2) are mainly attributed to close proximity of these households to water sources. In the case of using hired labor, the seasonal fluctuations in household labour demand and supply affect the cost. Because, in agrarian village economy, there is high demand for labour during the peak-farm season whereas excess labour supply is often the norm during off-peak farm season. Technical capacity of the household to undertake maintenance of the biogas system or availability biogas technicians at affordable price is another important factor in determining the cost and adoption of biogas technology (Biocrude Technology Inc., 2008).

Table 3 shows the PBP and NPV for the nine individual pilot households and to the households as a group. The results show that the PBP of investment for all the households more than the five years expected economic life of the digester. This means that all the nine households will take too long to pay back the start-up costs of investing in the digester. This is attributed to the initial investment cost for a flexible balloon digester, which although lower than other designs, remains too high to allow payback within the lifetime of the digester. In a field assessment of the performance of flexible balloon digesters in Kenya, GIZ (2010) estimated a PBP of 17 months. This is far lower than the estimates reported in the present study (minimum 5.2 years). The reason for such a large deviation may be explained by the fact that in this study we accounted for annual net saving whereas the study by GIZ (2010) used annual gross savings as the denominator in computing the PBP.

Table 3 further shows that all households experienced negative net present values despite a positive net annual savings. This implies the annual net savings are inefficient to cover the high initial investment costs of the technology, suggesting that it is not worthwhile to invest in a flexible balloon digester at the current investment cost. Similarly, the negative net present values of the households as a group is attributed to the high investment cost that outweigh the total financial benefits from using the digester.

Table 3. Net present values (NPV)

	Investment cost and net savings ('000 UGX) - substitution of biogas for fuelwood and kerosene						PV of net savings	NPV= (-) investment cost + PV net savings	PBP
HH.No.	Investment cost	Yr1	Yr2	Yr3	Yr4	Yr5	('000 UGX)		
HH1	(1333.00)	96	96	96	96	96	350.39	-982.61	13.9
HH2	(1333.00)	225	225	225	225	225	821.22	-511.78	5.9
HH3	(1333.00)	172	172	172	172	172	627.78	-705.22	7.7
HH4	(1333.00)	228	228	228	228	228	832.17	-500.83	5.8
HH5	(1333.00)	256	256	256	256	256	934.37	-398.63	5.2
HH6	(1333.00)	230	230	230	230	230	839.47	-493.53	5.8
HH7	(1333.00)	131	131	131	131	131	478.13	-854.87	10.2
HH8	(1333.00)	223	223	223	223	223	813.92	-519.08	6.0
HH9	(1333.00)	212	212	212	212	212	773.77	-559.23	6.3
All HHs	(11997.00)	1773	1773	1773	1773	1773	6471.23	-5525.77	6.8

Source: Survey data, 2013. Exchange rate 1 US $ = 2600 UGX

This is consistent to the findings of Bishop and Shumway (Bishop and Shumway, 2009), who also looked at the NPV of a tubular digester. White et al. (2011) used hypothetical molecular biogas digester and found that a biogas digester was financially viable. This was because the estimated capital for a hypothetical molecular biogas digester was based on the current available technology. However, Walekhwa (2010) and Winrock International (2007) both reported that fixed dome digesters were financially viable in Uganda. A fixed dome has a longer lifetime than a flexible balloon digester, being constructed from robust materials (like cement, sand, and gravel) and protected underground, rather than the less durable, puncture prone plastics used in the flexible balloon design.

4.2 Sensitivity analysis

The assumptions and economic variables used in the analysis may change over time. Therefore, a sensitivity analysis was conducted to test how sensitive the results are for changes in some of the values of the factors used in the analysis. We considered changes in investment cost and discount rate. The results of sensitivity analysis show that if the cost of the digester is reduced by 50%, the flexible balloon digester is financially viable for 67% of the induvial households and fully viable if all the study households are considered as a group in the study area (NPV= UGX5,804,730) (Table 4). However, reducing the discount rate by 50% shows that the digester still remains not viable financially for all experimental households (Table 4).

Table 4: Results of sensitivity analysis (Changes in NPV ('000 UGX))

HH.No.	NPV (at Current cost of investment) (UGX 1333000)	NPV (50% reduction investment cost) (UGX 666500)	NPV (50% reduction discount rate) (d=5.75%)
HH1	-982.61	-316.11	-925.85
HH2	-511.78	154.72	-378.74
HH3	-705.22	-38.72	-603.52
HH4	-500.83	165.67	-366.01
HH5	-398.63	267.87	-247.26
HH6	-493.53	172.97	-357.53
HH7	-854.87	-188.37	-777.41
HH8	-519.08	147.42	-387.22
HH9	-559.23	107.27	-433.87
All HHs	-5525.77	5804.73	-4477.41

Source: Survey data, 2013
Exchange rate 1 US $ = 2600 UGX.

4.3 Results from the survey of 'non-biogas' households

To understand the perception, attitudes and *ex ante* costs and benefits of flexible balloon biogas technology, 144 households not using the technology, but located in close proximities to the experimental households, were surveyed before and after the installation of biogas digesters in the study area. With regard the potential of biogas energy for cooking, 80.7% and 95.5% of the households, before and after the installation of the digesters respectively, perceived that biogas could replace fuelwood for cooking (Table 5). The increase in the number of respondents after the installation of the digesters is attributed to the neighborhood effect that cooking with biogas is more convenient and clean than fuelwood (Breffle et al., 1997; SNV, 2009). In addition, all the surveyed households reported they prefer to replace biogas energy for kerosene for lighting (Tooraj and Rabindra, 2010). This is explained by households' perceived energy cost reduction by shifting to biogas, assumed to be a 75% reduction of household lighting energy cost (Winrock International, 2007).

Table 5: Perception of non-biogas households on the benefits of flexible balloon digester

Use	Perception towards […]	Before installation (%)	After installation (%)
Cooking	• Use biogas for cooking all meals (Replace other sources of energy)	80.7	95.5
	• Use biogas for cooking some of the meals (will not completely replace other sources)	18.0	4.6
	• I would not use biogas for cooking meals at all (continue to use other energy sources)	1.3	
Lighting	• Replace current sources of lighting by biogas energy	72.3	100
	• Use biogas in addition to other sources of lighting	26.4	-
	• Will not use biogas for lighting at all	1.4	-

Source: Survey data, 2013

Table 6 shows the *ex-ante* analysis of the net present value (NPV) of flexible balloon biogas digester to non-biogas households. Both *ex ante* net annual savings and the NPV of substituting flexible balloon biogas technology to fuelwood energy are negative for an average household, suggesting that a flexible balloon digester would be not viable financially among the non-biogas households. Survey data shows that the biggest cost of this technology, about 60%, accounted for the initial cost of purchasing the technology.

Table 6. Net present value and payback period for non-biogas households

Items	Average amount ('000 UGX)	NPV ('000UGX)	PBP
Collecting water	249.6		
Collecting substrate	275.6		
Mixing feedstock	208		
Feeding the digester	174.2		
Subtotal (A)	**907.4**	-1,422.60	8.6
Fuelwood	555.6		
Kerosene	196.8		
Subtotal (B)	**752.4**		
Net saving ('000 UGX) substitution of biogas energy for fuelwood and kerosene (B-A)	-155		

Source: Survey data, 2013
Exchange rate 1 US $ = 2600 UGX

The payback period is 8.6 years is far greater than the economic life of a flexible balloon digester. This further signals the economic unviability of this technology, especially among the rural households with high time preference. Actually, the based on this results the biogas digester will wear out before the household recoup the investment cost. Overall, the results show adoption of this technology could worse off the household's welfare.

5. Conclusion

As it is the case in the majority of other African rural areas, fuelwood and kerosene are the dominant sources of cooking and lighting energy respectively in rural Uganda too. But using fuelwood for cooking has a number of disadvantages to the household and to the environment, such as poor indoor air quality and the consequent health impacts, labor time for fuelwood collection, deforestation, and environmental degradation. Similarly, use of kerosene for lighting is expensive given the meager income level of most rural households. Our findings indicate that local community have a good understanding of these impacts. This is demonstrated by their willingness and preferences to change from fuelwood and kerosene to biogas energy for cooking and lighting respectively. About 95% of survey households reveal their preferences to substitute clean and cheaper energy sources to their current energy sources. However, even a flexible balloon biogas digester which is claimed to be cheaper by many proponents of biogas technology compared other design e.g., fixed-dome design, is still not affordable to the majority of poor households. About 60% of the total cost of flexible balloon digester is accounted for by initial investment cost. Due to its high investment costs and relatively short life time and susceptibility to damage, investing in a flexible balloon digester is not viable financially and economically at smallholder household level.

The findings in this study uncover two major policy implications: (1) Despite the preferences among rural households to shift to renewable energy sources such as biogas energy, the high initial capital investment costs prevent access to the technology. Thus, if biogas industry is to succeed in Uganda and in other African countries with similar socio-economic conditions, any government agency or development partners promoting biogas energy should pay attention to the cost of technology and ensure its affordability to poor households through developing low cost locally manufactured digester and providing affordable financing mechanisms. (2) Because of the claim by certain donor organizations and other biogas technology proponents that flexible balloon digester is relatively cheap, there is an emerging tendency of recommending this technology to promote in rural Africa. However, the findings in this study shed lights that this technology is not viable financially and appears to be a risky investment. However, with a significant reduction in initial cost (up to 50% or above), the digester becomes financially viable among smallholder farm households. Compared to other biogas digesters such as the fixed dome model, flexible balloon biogas digester has shorter life time and it can be easily damaged (by children, domestic animals, pets, bad weather condition etc.). Thus, in addition to the cost aspect, promotion of biogas technology should take into account various contextual and environmental factors and whether the technology is viable in both short and long terms. Based on the finding in this study, smallholder farm households are not encouraged to invest in flexible balloon biogas digester at current investment cost unless there is a significant cut in the cost. Otherwise, options should be sought to finance digester designs, such as the fixed-dome designs, which are durable and less susceptible to damage by humans, animals, or environmental exposures.

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Appendix A: Designs of small scale biogas digester

The three main types of biogas digester designs available in Sub-Saharan Africa (SSA) are the flexible balloon, floating drum, and fixed dome (Figure A1). The choice of the design of the digester is a key determinant in the success of the implementation biogas technology; if it is too expensive, poor farmers cannot afford and will not be able to risk making the investment; but if it is not robust and cannot be easily repaired, farmers will not see the long term benefits. The flexible balloon installations are relatively cheap (30-100 US$), but are liable to damage. Floating drum and fixed dome digesters are more expensive (700-1200 US$), but are more robust. Floating drum installations are effective, providing gas with a fixed pressure, which is good for domestic use, but can be more expensive and less robust than a fixed dome digester. Fixed dome digesters are more robust as they use no moving parts and can be constructed from local materials. The different types of designs should be objectively evaluated for each installation to determine the most appropriate choice. The major factors that that determine the success of biogas interventions include: (i) Technical factors such as gas production, efficiency, and water requirements; (ii) economic or financial factors such as capital cost and operational costs; (iii) user factors and such as consumer satisfaction, time savings, and convenience; and (iv) institutional factors policy support and quality assurance system.

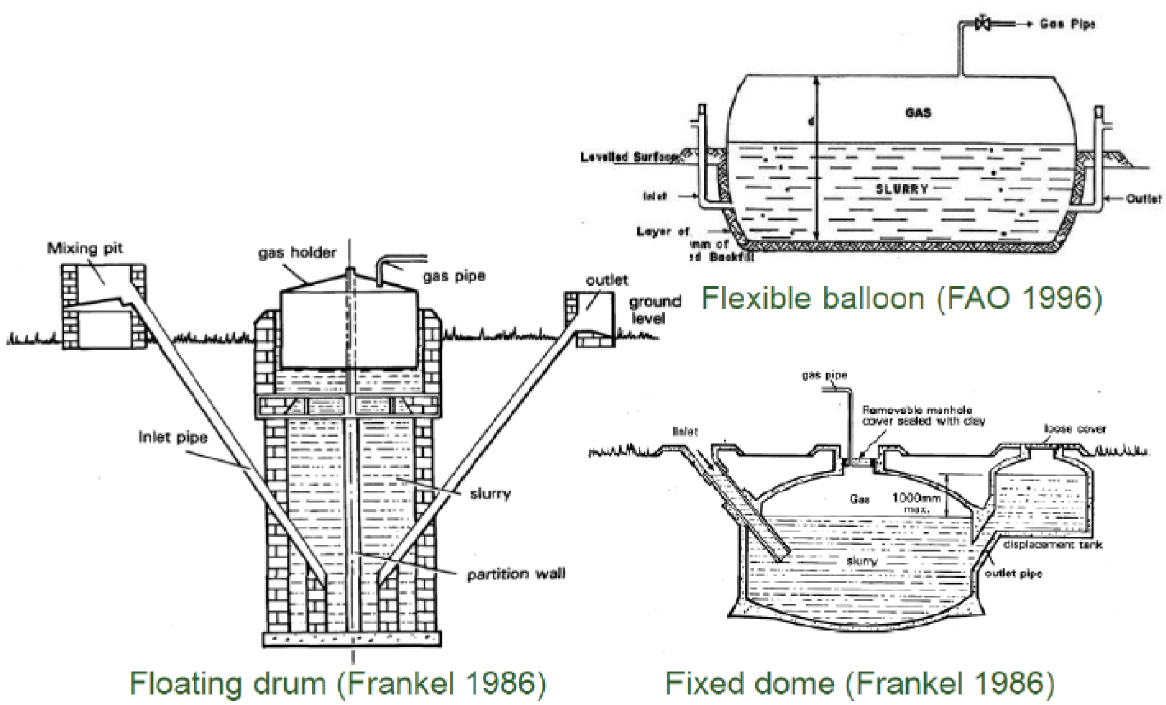

Figure A.1. Small scale biogas digester designs available in SSA.

Appendix B. Production of biogas energy production (experimental households)*

	Experimantal Households (HH)								
	HH 1	HH 2	HH 3	HH 4	HH 5	HH 6	HH 7	HH 8	HH 9
Biogas energy produced (in mega jolues per year (MJ/yr)	13,398	16,310	13,398	14,172	27,900	13,785	13,195	9,123	15,333
One kilowatt hour (KWh) of electricity is 3.6 megajoules.									
Energy in KWh	3,721.67	4,530.56	3,721.67	3,936.67	7,750.00	3,829.17	3,665.28	2,534.17	4,259.17
1 unit KWh in Ugandaof electricty equal 500 UGX									
Energy Vlaue ('000 UGX)	1,861	2,265	1,861	1,968	3,875	1,915	1,833	1,267	2,130

Sources*:

- Electricity costs in Uganda: http://www.monitor.co.ug/News/National/Electricity-tariffs-rise/688334-2480422-11ys7r0z/index.html
- The Potential of Small-Scale Biogas Digesters to Improve Livelihoods and Long Term Sustainability of Ecosystem Services in Sub-Saharan Africa Final Report – 14/06/13https: https://assets.publishing.service.gov.uk/media/57a08a1740f0b652dd000566/60928-FinalReport140613.pdf

Highlights

- We analyzed the economic potential of flexible balloon biogas design in Uganda.
- We used the tool of cost-benefit analysis using survey data from smallholder farmers.
- Households prefer to shift from fuelwood and kerosene to biogas for cooking and lighting.
- Investing in flexible balloon digester is not viable financially to smallholder farmers.