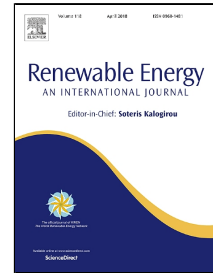


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Economic potential of flexible balloon biogas digester among smallholder farmers:  
a case study from Uganda



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

3  
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5  
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14  
15  
16 **Abstract**

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

32  
33  
34 **Keywords**

35 Biogas, cost-benefit analysis, economic viability, flexible balloon digester, Uganda  
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40

## 41 1. Introduction

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

53  
54 A study by Walekhwa et al. (2009) indicated that Uganda has a potential to generate 1740 Mtoe  
55 of energy from animal waste at a recoverable rate of 30%. If this energy is fully utilized, the  
56 health, economic and environmental outcomes of households would improve (Peipert et al.,  
57 2008). However, most efforts aimed at promoting biogas in Uganda have mainly focused on  
58 feasibility of the biogas production from two digester designs i.e., the fixed-dome and floating  
59 drum digesters (Walekhwa et al., 2009; Winrock International, 2007). However, these digester  
60 designs have proved to be too expensive for the average Ugandan to afford (Winrock  
61 International, 2007). Walekhwa (2010) reported that the total cost for the fixed doom plant range  
62 between UGX 6 - 20 million (ca. USD 2000-7000), depending on the size of the plant. This is  
63 beyond the reach of most households in a country where the national level per capita income is  
64 just about USD 770 (World Bank, 2014).

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

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

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<sup>1</sup>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.

<sup>2</sup> See appendix A for brief descriptions of the three most common biogas digester designs in use in Sub-Saharan Africa.

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

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

96  
97 This paper focuses on addressing two key questions related to the economic aspect of the flexible  
98 balloon design: (i) How do the economic cost of acquiring the technology including maintenance  
99 and operational costs compare to the costs saved and additional benefits accrued in using the  
100 flexible balloon digester? (ii) Do smallholder farm households better off by changing their  
101 domestic energy use from fuelwood to biogas? In order to address these questions, we applied a  
102 cost-benefit analysis.

## 103 **2. A brief overview of cost-benefit analysis**

104 CBA is an applied economic tool often used to guide the allocation of resource or investment  
105 decisions or policy alternatives or decisions involving the management of natural resources  
106 (OECD, 2006; Park and Oxon, 2012). It is a technique that is used to estimate and sum up (in  
107 present terms) of the future flows of benefits and costs of resource allocation decisions or policy  
108 alternatives to establish the worthiness of undertaking the stipulated alternative and inform the  
109 economic efficiency to the decision maker. The basic rationale for CBA is rooted in the  
110 ‘principle of potential compensation’ (Hicks, 1939; Kaldor, 1939). This principle states that an  
111 action is more efficient if those that are made better off could potentially compensate those that  
112 are made worse off. In situations where benefits and costs of an action are spread over time,

113 decisions are based on comparing the present value of benefits and costs. With regard to  
114 decisions related to technology adoption, the role of CBA is to measure the benefits and costs of  
115 technology adoption and consequently enables the comparison of the two systems – that with the  
116 proposed change and that of without it. The with-and-without approach is at the heart of the cost-  
117 benefit process.

118 CBA has been applied in the economic assessment of investment in various environmental and  
119 renewable energy technologies including biogas digesters. Kandpal et al (1991) used the CBA  
120 framework to analyze the economics of family-sized floating dome biogas digesters in India.  
121 Gwavuya et al (2012) and Walekhwa et al (2014) have applied the CBA tool to assess the  
122 economic potential of biogas technology as an alternative source of household energy in Ethiopia  
123 and Uganda respectively. Using a case study in Valmiera city in Latvia, Dobraja et al (2016)  
124 applied CBA to evaluate the economic value of environmental aspects of waste-to-energy  
125 process to guide prioritization of investment options. Zhang and Chen (2016) used a modified  
126 version of the traditional CBA and applied energy-based CBA to conduct a comprehensive  
127 assessment of the economic and ecological performance of urban biogas project. Wresta et al  
128 (2015) implemented the tool of CBA in the economic analysis of cow manure biogas as energy  
129 source in small scale ranch. Most recently, Abbas et al (2017) employed a benefit-cost ratio  
130 decision criteria to estimate the financial benefits of adoption of biogas technology by rural  
131 farmers in Pakistan.

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

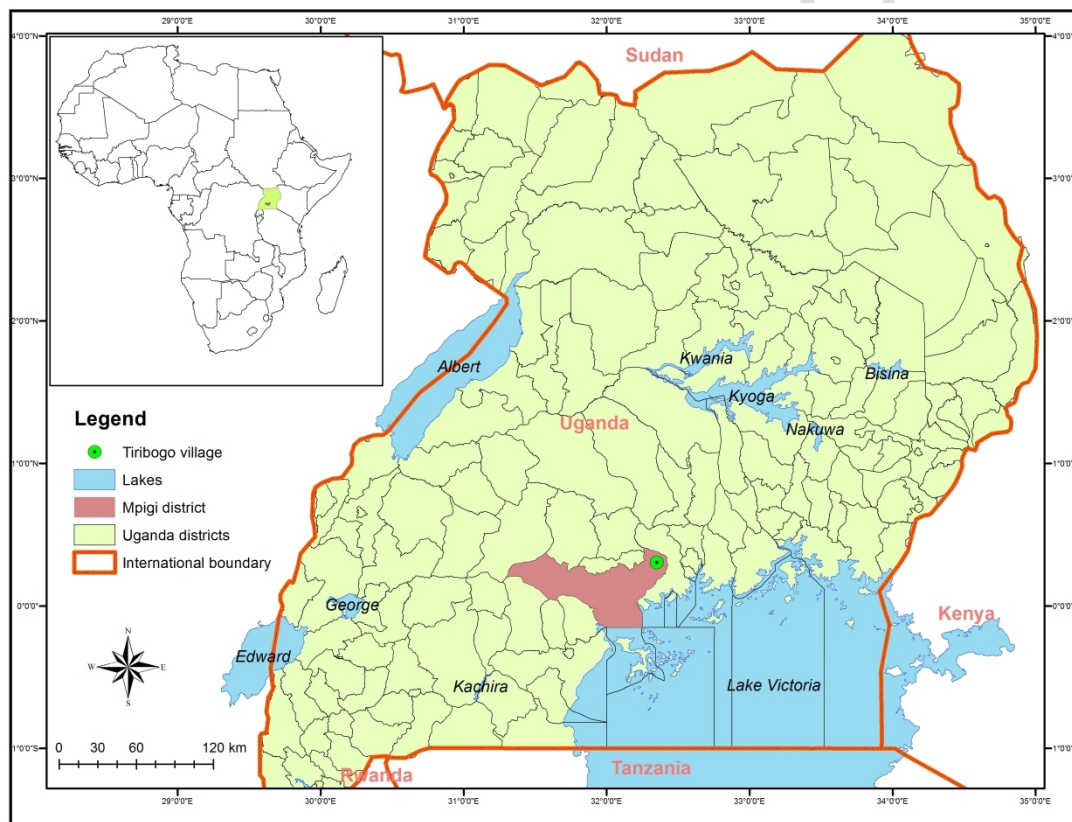
144  
145 This study applied the CBA using empirical data on costs and benefits obtained from the  
146 experimental households in Tiribogo community (south-west Uganda) and questionnaire survey  
147 of sampled households in the vicinity of the experimental community in Mpigi district (Uganda).  
148 The method of estimating the cost and benefit items are detailed in section 3.3.

149

### 150 3. Materials and Methods

#### 151 3.1 Description of the Study Area

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



160  
 161 Figure 1. Map showing the study area  
 162

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

169 (*Amaranthus caudatus*) while coffee (15,000 Mt) is the main cash crop grown. The animals  
170 reared and their respective population include pigs (108,082), goats (102,828) and cattle  
171 (216,621), and these were reared on small scale with most households keeping at least one of  
172 these animals. Tiribogo village has no grid connection and the main source of energy used for  
173 lighting is kerosene. Most of the household use fuelwood as their main source of energy for  
174 cooking, although some of the households use charcoal for cooking. Fuel wood and charcoal are  
175 the main source of energy for cooking because the village is bordered by the forest where trees  
176 are cut and used for fuelwood and charcoal. Institutions like schools consume a lot of fuelwood  
177 energy for preparing students meals.

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

### 184 **3.2 Sampling and field data collection**

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

197  
198 Once the pilot households identified, farm household data were collected in two different  
199 timelines: (i) Baseline survey (before digester installation): a baseline survey was conducted in  
200 July 2013 to determine the situation before the digesters were installed with the nine households  
201 selected. The sampling frame for the baseline survey included the nine experimental households  
202 and 144 randomly selected other households that were within a close proximity of each of the  
203 nine households i.e., 16 randomly selected households to each pilot household based on  
204 community's local council register. A face-to-face structured questionnaire interview was  
205 administered by the first author (as part his graduate study research) and supervised by his  
206 advisors. (ii) The second round follow-up survey was conducted six months after the installation

207 of biogas digesters. This was to give time for the pilot households to undergo a change in living  
208 as a result of using biogas. The follow-up survey on the nine pilot households was focused on the  
209 use of biogas energy, feedstock supply, changes in the household's labour demand and other  
210 resources. All the 144 'non-biogas' households included in the baseline were also interviewed in  
211 the follow-up survey to understand neighborhood effects and the likelihood of technology  
212 adoption.  
213

### 214 **3.3 Estimation of the cost and benefit items**

215 The major cost components of the flexible balloon digester include the investment cost incurred  
216 to acquire the digester and operational and maintenance costs. The key part of operational cost is  
217 household labour time on various activities such as water collection, collecting substrate, mixing  
218 feedstock and feeding the digester. The operational costs were obtained by asking the farmers  
219 with digesters how much time they spent on carrying out these activities each time they fed the  
220 digester.  
221

222 The benefits gained include biogas for cooking and lighting, use of slurry as a fertilizer,  
223 improvement in health and hygiene, and sale of the biogas produced by the household (if they  
224 manage to produce biogas more than the household demand). Biogas benefits in the form of  
225 'reduced costs' due to the substitution of biogas to fuelwood and kerosene are the most important  
226 benefit items. The reduced costs comprises of the reduction in labour for fuelwood collection and  
227 the cost of kerosene saved. There exists rural labor market in Tiribogo area partly due to the  
228 proximity of the area to nearby population centres. The local rural wage daily rate of 5000  
229 Ugandan shillings (UGX<sup>3</sup>) for unskilled workers was used to convert labour time into monetary  
230 value estimates.  
231

232 In order to determine the value of the reduced labour cost for fuelwood collection or expenditure  
233 on fuelwood, households were asked the frequency of fuelwood collection each month or the  
234 amount they spend if they would buy fuelwood before and after they installed the digester. These  
235 information were captured in the baseline as well as follow-up surveys. The time saved from  
236 fuelwood collection was determined as the difference between the time spent for fuelwood  
237 collection before and after the installation of the digester.  
238

239 Reduced costs on kerosene are costs that would no longer be spent on buying kerosene if light is  
240 provided by biogas. Savings made from replacing kerosene for lighting with biogas were  
241 determined as the difference between the amount spent on kerosene before installation and after  
242 installation of the digesters.  
243

---

<sup>3</sup>This wage rate is for 6 hours of effective work time. 1USD is about 2600 UGX during the survey time.



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

255  
256 On the other hand flexible balloon digesters have certain technical difficulties which may  
257 undermine adoption of these technologies. The plastic tube is vulnerable to damage if not  
258 adequately protected from animals and other potential hazards. It can be easily damaged by  
259 animals, humans (children), sharp objects, etc. It can be also degraded by prolonged exposure to  
260 Ultraviolet (UV) light. Flexible tube digesters have a constant volume, which means that the  
261 biogas produced has a variable pressure, depending on the volume of gas in the digester. After  
262 prolonged periods of cooking, the gas pressure can drop. The gas pressure and activity of the  
263 micro-organisms decomposing the organic waste are also more affected by changes ambient  
264 temperatures than in designs with better insulation, such as fixed dome digesters that are  
265 constructed underground. The pipe that transports the gas from the digester to the kitchen can  
266 bend, leading to possible blockage of the gas line.

### 268 **3.4 Analytical approach**

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

---

<sup>4</sup> 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.

$$278 \quad NPV = -INV + \sum_{k=1}^n \frac{CF_k}{(1+d)^k} \text{-----} (1)$$

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

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

$$291 \quad PBP = IC / CF \text{-----} (2)$$

## 292 **4. Results and discussion**

### 293 **4.1 Results from the survey of experimental households**

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

305  
 306 The findings furthermore reveal that households reported were willing to pay UGX 135,000 (just  
 307 over USD 50 per digester) to purchase a new flexible balloon digester. Considering the actual  
 308 cost of a flexible balloon digester (UGX 1,332,630), ca. USD 500, it portrays that the amount  
 309 households were willing to pay for a new digester is 10 times less than the actual cost of the  
 310 digester. The high actual cost is attributed to importation and the low willingness to pay can be  
 311 explained by the low household income.

312 Table 1 indicates that cooking with biogas takes more time than using fuelwood for all meals  
 313 except breakfast though the latter is not statistically significant. The results show that cooking  
 314 using fuelwood takes shorter time than that of biogas. The intensity of the flame obtained with  
 315 fuelwood can be increased to produce hotter flame by feeding the fire, whereas the intensity of  
 316 flame produced by biogas cannot be increased to suit for a bigger cooking utensils coupled with  
 317 small cooking stove. The calorific value of 1m<sup>3</sup> of biogas is 20 MJ and its burning efficiency is  
 318 34% (Gwavuya et al. 2012) but gas production from the plastic digester can be affected by  
 319 unfavorable weather condition (Agrahari and Tiwari, 2013) whereas 1 kg of firewood has an  
 320 average calorific value of 18 MJ and a use efficiency of about 10% (Gwavuya et al. 2012). This  
 321 means that provided fuelwood is dry, addition of more fuelwood to the stove will likely increase  
 322 the calorific value which makes cooking faster. With regard to cooking breakfast, surveyed  
 323 households claim that school children and household members working off-farm leave the house  
 324 early in the morning and they are not served with freshly cooked breakfast. So, cooking breakfast  
 325 for the remaining few members of the household using a small saucepan well suited to the small  
 326 cooking stoves with biogas energy takes a shorter cooking time than that of fuelwood (Table 1).  
 327

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

Meal	Fuelwood		Biogas		Mean sum of square		Test		
	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

330 Source: Survey data, 2013; Std= standard deviation

331 The finding in this study (in relation to cooking time) is in contrast to the findings in a number of  
 332 studies. For instance, the study by SNV (2009) in Bangladesh reported that 48.6 minutes were  
 333 saved every day by converting to biogas (SNV, 2009). Similarly, Walekhwa (2010), Agrahari  
 334 and Tiwari (2013), and Garfi et al., (2011) have shown that cooking using biogas takes shorter  
 335 time than cooking using fuelwood. Moreover a study in the Peruvian Andes involving 12 rural  
 336 families in a project to substitute biogas for firewood, showed a decrease of firewood  
 337 consumption by 50%–60% and cooking time by 1 hour (Garfi et al., 2011). The likely reason for  
 338 the divergence is attributed to the digester design and the small size of cook stove used in this

339 study area which may necessitate cooking more than once in some households to serve a meal  
340 for a large household size. Fact Foundation (2012) reported that when selecting a stove, it is  
341 important to determine the required power and small stove size could increase cooking time in  
342 comparison to the traditional way of cooking.

343  
344 In designing a low cost biogas pressurizing system, similar to the one used in this study but with  
345 slight modification, Geiger and Regan (2014) conducted an experiment to test the time taken  
346 while cooking 0.45 kg of dry beans using the wood burning stove and the biogas digester in  
347 Nicaragua. The results revealed that it took 120 and 105 minutes to cook 0.45 kg of dry beans  
348 using the wood burning stove and biogas digester respectively. The time taken in cooking lunch  
349 and supper using fuelwood in this study is slightly lower than that of the study conducted by  
350 Geiger and Regan (2014), by 6 and 12 minutes respectively (Table 1). Whereas cooking using  
351 biogas in Geiger and Regan (2014) experimental test takes a shorter time than in this study,  
352 because the digester in their experiment was designed to regulate and avoid gas losses and thus  
353 more gas was available and this took less time to cook. Another reason for the discrepancy could  
354 be the inefficiencies of a plastic digester such as failure to maintain gas for a long period. For  
355 instance, Njoroge (2002) observed that with a tubular plastic digester, there could be problems in  
356 maintaining high gas pressure for the extended period of time needed to cook a typical meal,  
357 suggesting that cooking food using biogas from a tubular plastic digester is likely to take a longer  
358 time than using other biogas digester designs. Agrahari and Tiwari (2013) also reported that  
359 fluctuations in gas production, especially in the morning and late evenings, are very inconvenient  
360 and result in a longer cooking hours. The issue of low gas production in the morning and evening  
361 is based on how well the digester is insulated from weather elements, such as sun, rain, and  
362 wind.

363  
364 Table 2 shows the costs and net savings by an individual household substituting biogas energy  
365 from flexible balloon digester for both fuelwood (cooking energy) and kerosene (lighting). All  
366 the nine households using the biogas had a positive net annual savings as a result of substituting  
367 biogas for fuelwood and kerosene.

368

370 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

371 Source: Survey data, 2013

372 Exchange rate during the survey period: 1US \$ = 2600 UGX

373

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

384

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

396

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

403

404 Table 3. Net present values (NPV)

HH.No.	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
	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

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

406

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

416 **4.2 Sensitivity analysis**

417 The assumptions and economic variables used in the analysis may change over time. Therefore, a  
 418 sensitivity analysis was conducted to test how sensitive the results are for changes in some of the  
 419 values of the factors used in the analysis. We considered changes in investment cost and discount  
 420 rate. The results of sensitivity analysis show that if the cost of the digester is reduced by 50%, the  
 421 flexible balloon digester is financially viable for 67% of the individual households and fully viable

422 if all the study households are considered as a group in the study area (NPV= UGX5,804,730)  
 423 (Table 4). However, reducing the discount rate by 50% shows that the digester still remains not  
 424 viable financially for all experimental households (Table 4).

425  
 426 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

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

#### 429 4.3 Results from the survey of 'non-biogas' households

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

443 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	-

444 Source: Survey data, 2013

445

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

452 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		
<b>Subtotal (A)</b>	<b>907.4</b>		
Fuelwood	555.6	-1,422.60	8.6
Kerosene	196.8		
<b>Subtotal (B)</b>	<b>752.4</b>		
Net saving ('000 UGX) substitution of biogas energy for fuelwood and kerosene (B-A)	-155		

453 Source: Survey data, 2013

454 Exchange rate 1 US \$ = 2600 UGX

455

456 The payback period is 8.6 years is far greater than the economic life of a flexible balloon  
 457 digester. This further signals the economic unviability of this technology, especially among the



458 rural households with high time preference. Actually, the based on this results the biogas digester  
459 will wear out before the household recoup the investment cost. Overall, the results show  
460 adoption of this technology could worse off the household's welfare.

## 461 **5. Conclusion**

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

478  
479 The findings in this study uncover two major policy implications: (1) Despite the preferences  
480 among rural households to shift to renewable energy sources such as biogas energy, the high  
481 initial capital investment costs prevent access to the technology. Thus, if biogas industry is to  
482 succeed in Uganda and in other African countries with similar socio-economic conditions, any  
483 government agency or development partners promoting biogas energy should pay attention to the  
484 cost of technology and ensure its affordability to poor households through developing low cost  
485 locally manufactured digester and providing affordable financing mechanisms. (2) Because of  
486 the claim by certain donor organizations and other biogas technology proponents that flexible  
487 balloon digester is relatively cheap, there is an emerging tendency of recommending this  
488 technology to promote in rural Africa. However, the findings in this study shed lights that this  
489 technology is not viable financially and appears to be a risky investment. However, with a  
490 significant reduction in initial cost (up to 50% or above), the digester becomes financially viable  
491 among smallholder farm households. Compared to other biogas digesters such as the fixed dome  
492 model, flexible balloon biogas digester has shorter life time and it can be easily damaged (by  
493 children, domestic animals, pets, bad weather condition etc.). Thus, in addition to the cost aspect,  
494 promotion of biogas technology should take into account various contextual and environmental  
495 factors and whether the technology is viable in both short and long terms. Based on the finding in

496 this study, smallholder farm households are not encouraged to invest in flexible balloon biogas  
 497 digester at current investment cost unless there is a significant cut in the cost. Otherwise, options  
 498 should be sought to finance digester designs, such as the fixed-dome designs, which are durable  
 499 and less susceptible to damage by humans, animals, or environmental exposures.

500

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507

### 508 **REFERENCES**

509

510 Abbas, T., Ali, G., Adil, S.A., Bashir, M.K., Kamran, M.A., 2017. Economic analysis of biogas  
 511 adoption technology by rural farmers: The case of Faisalabad district in Pakistan.

512 *Renewable Energy* 107:431-439.

513 Agrahari R.P, Tiwari G. N, 2013. The Production of Biogas Using Kitchen Waste. *International*  
 514 *Journal of Energy Science (IJES)* 3:6-10.

515 Biocrude Technology Inc, 2008. Study on implementing Biocrude technologies in the  
 516 transformation of organic waste into usable and marketable products. Technical Report.

517 [http://www.biocrudetech.com/portal/index.php?option=com\\_docman&task=cat\\_view&gid=41&Itemid=74](http://www.biocrudetech.com/portal/index.php?option=com_docman&task=cat_view&gid=41&Itemid=74) (accessed 05 Sept 2016).

519 Bishop, C. P., Shumway, R., 2009. The economics of dairy anaerobic digestion with co product  
 520 marketing. *Applied Economic Perspectives and Policy* 31:394-410.

521 Breffle, W. S., Morey, E.R., Lodder, T.S., 1997. Using Contingent Valuation to Estimate a  
 522 Neighbourhood’s Willingness to Pay to Preserve Undeveloped Urban Land. Department  
 523 of Economics, University of Colorado.

524 <http://www.colorado.edu/economics/morey/4535/cunning.pdf> (accessed 04 Sept. 2016)

525 da Silva, I.P, Sendegeya, A., 2006. Benefits of using biogas in Households: Experience from a  
 526 user in Uganda. Makerere University. Benefit biogas docum027A\_sendegeya.pdf.

527 FACT Foundation, 2012. Manual for the construction and operation of small and medium size  
 528 biogas systems. Bilibiza, Gabo Delgado, Mozambique.

529 Garfi, M.; Ferrer, I.; Uggetti, E.; Ferrer-Martí, L.; Calderon, A.; Velo, E. Biogas production in  
 530 low-cost household digesters at the Peruvian Andes. *Biomass Bioenergy* 35:1668–1674.

531 Geiger, L .R., Regan, K B., 2014. Designing a Low Cost Biogas Pressurizing System in  
 532 Nicaragua. Iowa State University.

533 GIZ, 2010. Survey of Plastic Tube Digesters in Kenya. Technical Report. Nairobi, Kenya.

534 Gwavuya, S.G., Barfuss, I, Zeller, M., Müller, J., 2012. Household energy economics in rural  
 535 Ethiopia: A cost-benefit analysis of biogas energy. *Renewable Energy* 48: 202-209.

536 Hicks J.R., 1939. Value and capital. Chapter II. The Law of Consumer’s Demand.

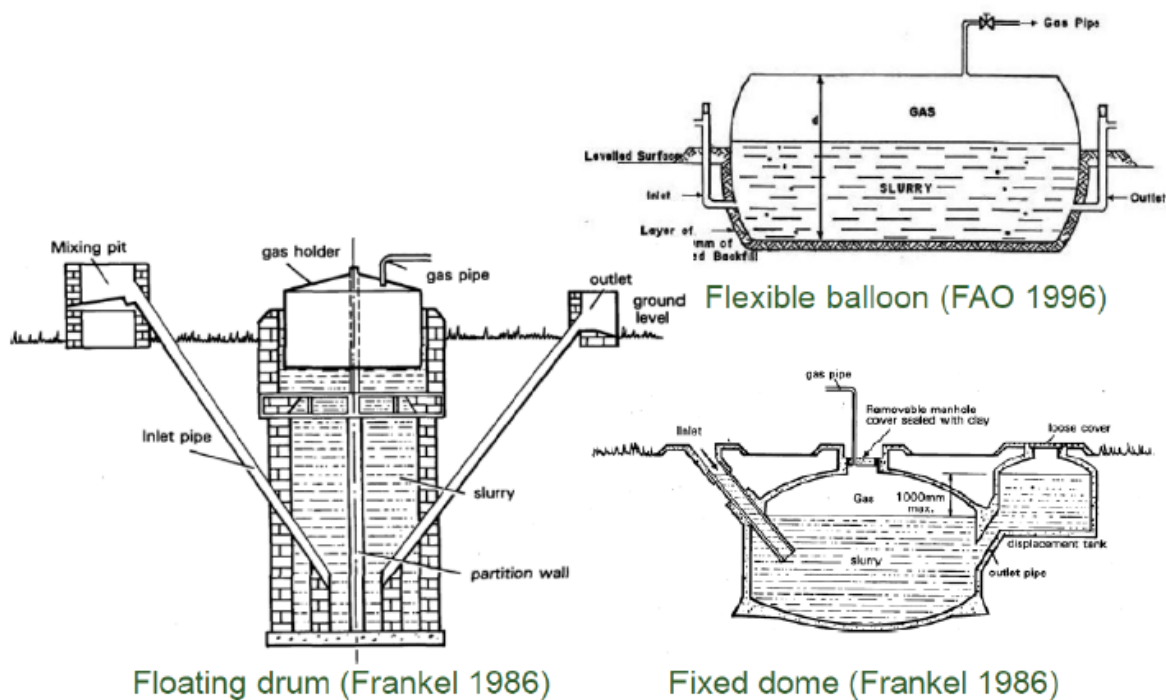
537 <http://la.utexas.edu/users/hcleaver/368/368hicksVCdemand.pdf>. (accessed 04 Sept 2016)

- 538 Kaldor N., 1939. Welfare propositions of economics and interpersonal comparisons of utility.  
 539 *The Economic journal* 49:549-552.
- 540 Ministry of Finance, Planning and Economic Development (MFPED), 2002. Uganda Population  
 541 and Housing Census, 2002. Final Report.  
 542 [http://www.ubos.org/onlinefiles/uploads/ubos/pdf%20documents/2002%20Census%20Fi](http://www.ubos.org/onlinefiles/uploads/ubos/pdf%20documents/2002%20Census%20Final%20Reportdoc.pdf)  
 543 [nal%20Reportdoc.pdf](http://www.ubos.org/onlinefiles/uploads/ubos/pdf%20documents/2002%20Census%20Final%20Reportdoc.pdf). (accessed 30 Aug 2016)
- 544 Njoroge D. K., 2002. Evolution of biogas technology in South Sudan: Current and future  
 545 challenges. Proceedings Biodigester workshop March 2002. Ho Chi Minh City,  
 546 Vietnam.
- 547 OECD, 1984. Biomass for energy: economic and policy issues. OECD Publications and  
 548 Information Center. Washington, D.C.
- 549 OECD, 2006. *Cost-Benefit Analysis and the Environment: Recent Developments*, OECD  
 550 Publishing, Paris. <http://dx.doi.org/10.1787/9789264010055-en>
- 551 Park, M., Oxon, A. 2012. *Cost-Benefit Analysis: Cases and Materials*. Routledge. New York.
- 552 Peipert, J., Severyn, T., Hovmand, P.S., Yadama, G.N., 2008. Modelling the Dynamics of the  
 553 Energy, Environment, and Poverty Nexus: A Study of Biogas Unit Diffusion in Andhra  
 554 Pradesh, India. Research Report. Washington University in St. Louis. USA.
- 555 Sabah, A., Jeanty, P.W., 2011. Willingness to pay for renewable energy: Evidence from a  
 556 contingent valuation survey in Kenya. *Renewable and Sustainable Energy Reviews*  
 557 15:2974– 2983.
- 558 Shrestha, A., 2010. Prospects of biogas in terms of socio-economic and environmental benefits  
 559 to rural community of Nepal: A case of biogas project in Gaikhur VDC of Gorkha  
 560 district. MSc Thesis. Tribhuvan University.
- 561 Singh, K. J., Sooch, S. S., 2004. Comparative study of economics of different models of family  
 562 size biogas plants for state of Punjab, India. *Energy Conversion & Management* 45:1329-  
 563 1341.
- 564 SNV, 2009. Biogas Users Survey in Bangladesh. Technical Report.  
 565 [http://www.snv.org/public/cms/sites/default/files/explore/download/annual\\_biogas\\_users](http://www.snv.org/public/cms/sites/default/files/explore/download/annual_biogas_users_survey_-_bangladesh_2010.pdf)  
 566 [survey - bangladesh 2010.pdf](http://www.snv.org/public/cms/sites/default/files/explore/download/annual_biogas_users_survey_-_bangladesh_2010.pdf) (accessed 05 Sept 2016).
- 567 Tooraj, J., Rabindra, N., 2010. Issues and options in waste management: A social cost–benefit  
 568 analysis of waste-to-energy in the UK. *Resources, Conservation and Recycling* 54:1341–  
 569 1352.
- 570 Walekhwa P.N., 2010. Socio-Economic assessment of biogas production and utilization from  
 571 Family sized bio digesters in Uganda. Makerere University, PhD thesis.
- 572 Walekhwa, P. N., Drake L., Mugisha J., 2014. Economic viability of biogas energy production  
 573 from family-sized digesters in Uganda. *Biomass and Bioenergy* 70: 26-39.
- 574 Walekhwa, P. N., Mugisha, J., Lars, D., 2009. Biogas energy from family-sized digesters in  
 575 Uganda: Critical factors and policy implications. *Energy Policy* 37:2754-2762.
- 576 White, A. J., Kirk, D. W., Graydon, J. W., 2011. Analysis of small-scale biogas utilization  
 577 Systems on Ontario cattle farms. *Renewable Energy* 36:1019-25.
- 578 Winrock International., 2007. Biogas for Better Life - An African Initiative. A Cost-Benefit  
 579 Analysis of National and Regional Integrated Biogas and Sanitation Programs in Sub-  
 580 Saharan Africa. A discussion paper. Winrock International, Denmark.
- 581 World Bank., 2014. World Development Indicators.  
 582 <http://databank.worldbank.org/data/reports.aspx?Code=NY.GNP.PCAP.CD&id=1ff4a49>

- 583 [8&report\\_name=Popular-](#)  
584 [Indicators&populartype=series&ispopular=y#selectedDimension\\_WDI\\_Ctry](#) (accessed  
585 27 July 2017).
- 586 Wresta, A., Andriani, D., Saepudin, A., Sudiby, H., 2015. Economic Analysis of Cow Manure  
587 Biogas as Energy Source for Electricity Power Generation in Small Scale Ranch. *Energy*  
588 *Procedia* 68: 122-131.
- 589 Zhang B., Chen, B., 2016. Energy-based cost-benefit analysis for urban biogas project. *Energy*  
590 *Procedia* 88:119-125.
- 591

## 593 Appendix A: Designs of small scale biogas digester

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



610

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

612

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

	Experimental Households (HH)								
	HH 1	HH 2	HH 3	HH 4	HH 5	HH 6	HH 7	HH 8	HH 9
Biogas energy produced (in megajoules 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 Uganda of electricity equal 500 UGX									
Energy Value ('000 UGX)	1,861	2,265	1,861	1,968	3,875	1,915	1,833	1,267	2,130

615  
616617 **Sources\*:**

- 618 • Electricity costs in Uganda: <http://www.monitor.co.ug/News/National/Electricity-tariffs-rise/688334-2480422-11ys7r0z/index.html>
- 619 • The Potential of Small-Scale Biogas Digesters to Improve Livelihoods and Long Term Sustainability of Ecosystem Services in Sub-Saharan Africa Final Report – 14/06/13 <https://assets.publishing.service.gov.uk/media/57a08a1740f0b652dd000566/60928-FinalReport140613.pdf>
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- 623

## 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.