SECURING WATER FOR FOOD

# GreenHeat Performance Evaluation

## Slurry-Separation Technology (SST) Biogas Systems in Uganda

AUGUST 2019

SECURING WATER FOR FOOD: A GRAND CHALLENGE FOR DEVELOPMENT

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# TABLE OF CONTENTS

# ABSTRACT

Green Heat was sponsored by SWFF to reach more farmers with their innovative Slurry-Separation Technology (SST) biogas systems in Uganda and beyond. The technology was intended to separate water from the waste to be reused for mixing. In addition to recycling water, the SST was expected to create an easily managed high-quality fertilizer product while increasing gas production for energy consumption. This field evaluation was conducted to evaluate the performance of biogas technology in general and the slurry-separation innovation in particular. The survey was conducted July through August, 2019, in Uganda, four years after the introduction of the slurry-separation innovation.

The sample respondents interviewed included 51 percent men and 49 percent women. Thirteen districts from across all four regions of Uganda were covered. Farmers' experience with biogas technology ranged from two months to 11 years.

Through face-to-face interviews, respondents reported benefits of the innovation were energy for cooking and lighting, soil fertility and productivity, household income improvement, and environmental sustainability. Fifty-four percent of farmers reported very significant improvement in their household income, while 96 percent confirmed improvements in the survival rate of their crops. However, the innovation's impact on water consumption was not as promising. Of the interviewees, 61 percent reported their water consumption was increased due to the innovation. This was mainly attributed to the amount of water required to mix cow dung. Biodigesters equipped with SST contribute toward achieving most of the UN Sustainable Development Goals (SDGs). However, this survey confirmed that slurry-separation systems were not properly used in the biogas plants visited. No communal or individual negative impact resulted from biogas or the SST.

# INTRODUCTION

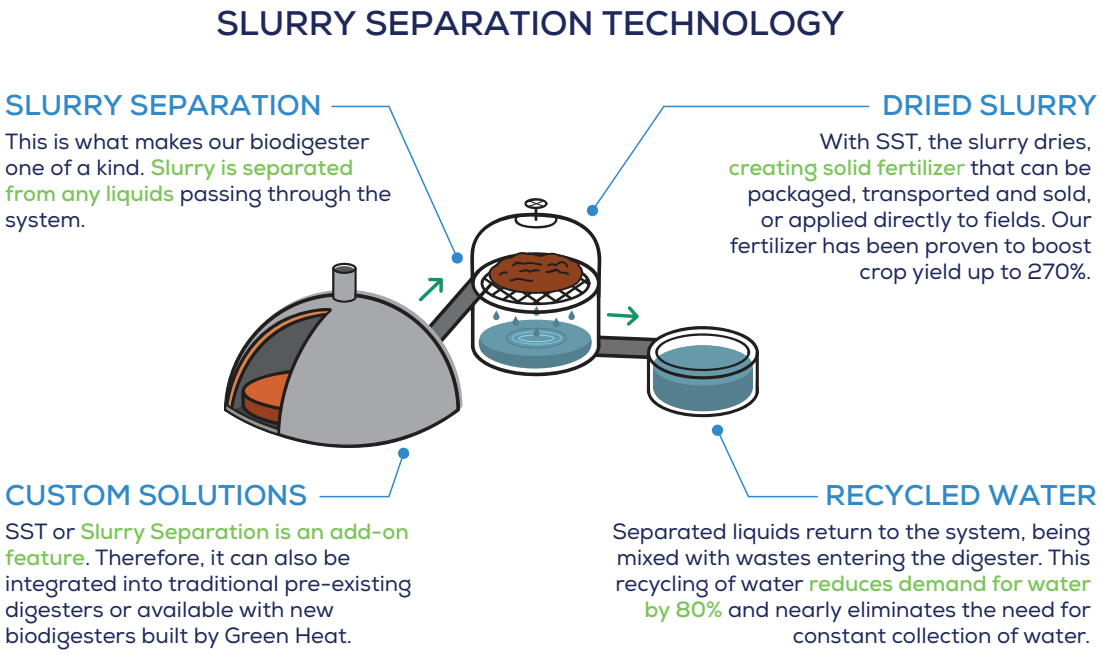
The Food and Agriculture Organization (FAO) estimates that more than one-half of the developing world's population, or 45 percent of all humanity, is rural dwellers and about 2.5 billion depend directly on farming for their livelihoods. As global pollution continues to grow, demand for food also is surging. However, the agriculture sector is facing numerous challenges – climate variability, shortage of water, pollution, land degradation, etc. In addition, rural people in developing countries rely mainly on fuelwood and/or charcoal for cooking, heating, and lighting as they have little or no access to modern energy. This not only exacerbates deforestation and the impact of climate variability but also causes negative effects on health, labor, and time spent on agricultural activities for women and children.

Agriculture is known to be both the victim and the cause of water scarcity globally. On one hand, the sector is the largest water consumer, while on the other it is the main source of water pollution. Therefore, the agricultural sector holds the key to tackling water scarcity and sustainability of livelihoods reliant on water and agriculture. Biogas generated through anaerobic digestion of organic materials from human and animal waste, crop residue, agro-industrial waste, and other biomass materials could contribute to this end. Biogas digesters could provide three main benefits – energy security, food security, and environmental sustainability. As a result, demand for the technology has grown steadily. In Uganda, biogas innovations have a long history despite the country's low adoption rate. To date, about 5,800 domestic biogas plants have been installed throughout the country since the technology was introduced in 1950[1]. Unfortunately, 50 percent of them fail within one year due to high water demand that is mostly attributed to a wasteful design.

1 Tumusiime, Edmund, John B Kirabira, and Wilson B Musinguzi. 2019. "Long-Life Performance of Biogas Systems for Productive Applications : The Role of R & D and Policy." *Energy Reports* 5: 579–83. https://doi.org/10.1016/j.egyr.2019.05.002.

To address this challenge, Green Heat Uganda LTD introduced an innovative Slurry-Separation Technology (SST) to reduce water consumption by biogas plants (Figure 1). The technology creates an easily managed fertilizer while increasing gas production. The innovation separates water from the slurry to create solid fertilizer. The dry organic fertilizer can be packaged, stored, or applied directly to farm fields. The liquid is reused to mix wastes, replacing the need for freshwater. Green Heat provides biodigesters already equipped with slurry separation; however, the innovator also integrates its SST innovation to existing digesters. According to Green Heat, while other digesters require one liter of water for mixing every kilogram of waste, its digesters dramatically reduce freshwater usage because water is recycled through the SST. Moreover, Green Heat's biodigesters can be fed a variety of liquids, such as rainwater, wastewater, and cow urine. The system is said to be eco- and gender-friendly, efficient, and a true cost-saver.

**FIGURE 1. GREEN HEAT'S SST[2]**




2 Http://Www.Greenheatinternational.Com/Biogas/

Green Heat has rapidly increased its scope in terms of geography and product types. While the company is headquartered and mainly focused in Uganda, it has started to expand its market by installing some biogas systems in other countries, including Ethiopia, Mozambique, Rwanda, Togo, and Haiti. Furthermore, apart from its innovative digester, Green Heat is actively engaged in producing and distributing efficient briquettes and solar lamps, and finding ways to store the methane gas from digesters.

In 2015, Green Heat secured funds from the Securing Water for Food: A Grant Challenge for Development (SWFF) specifically to introduce the slurry separation system to more biogas plants. This field evaluation was, therefore, conducted as SWFF seeks to understand the innovator's reach, barriers to adoption, and economic and development performance. The survey was intended to collect independent data directly from end users to provide a historical perspective on funding sustainability.

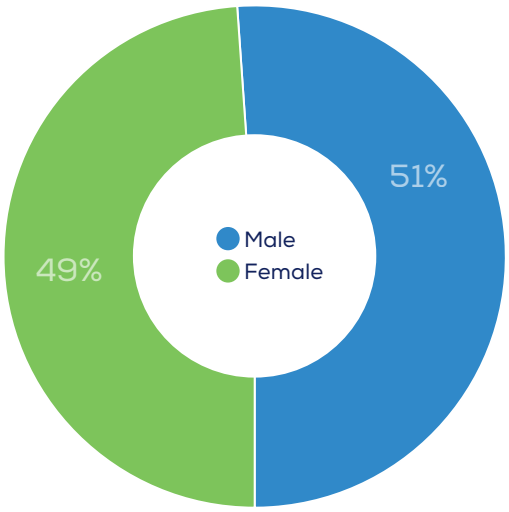
# BACKGROUND

The Republic of Uganda is administratively divided into four regions – Central, Eastern, Northern, and Western. These regions are subdivided into districts. The field survey attempted to cover all regions by taking sample districts. Data was collected by using the Fulcrum mobile application. All interviews were recorded, and the photos were taken using Dropbox. Questions addressed these main issues: benefits of biogas on overall customers' livelihoods; impact of innovation on crop yield and household income; challenges users face while using the technology; impact of biogas technology on water consumption; impact of innovation on inputs, such as fertilizer and charcoal; any negative impact imposed by the technology in communities; and, contribution of the innovation to women's activities and empowerment.

## Gender

The initial list of customers was composed of 1,177 individual households. Male clients accounted for 52 percent (610), while females made up 48 percent (567).

**FIGURE 2. GENDER OF RESPONDENTS (N=57)**



While interviewing both male and female clients was mandatory, no preferential treatment was required to incorporate more women since their size was equivalent to their male counterparts. Respondents were selected from both genders proportional to the total clients. Therefore, the sample also consisted of 52 percent (32 out of 60) male and 48 percent (28 out of 60) female respondents – with similar equivalency between both sides. However, the interviewed clients changed to 51 percent (29 out of 57) male and 49 percent (28 out of 57) female (Figure 2). The small disparity was due to absentees and/or additional females who took part in the interview.

## Farm size

Studies show that 85 percent of the farming communities in Uganda are smallholders. The average farm size held by these farmers is 2.5 hectares. Statistical analysis was carried out to determine interviewees' farm plot size data patterns and trends (Table 1).

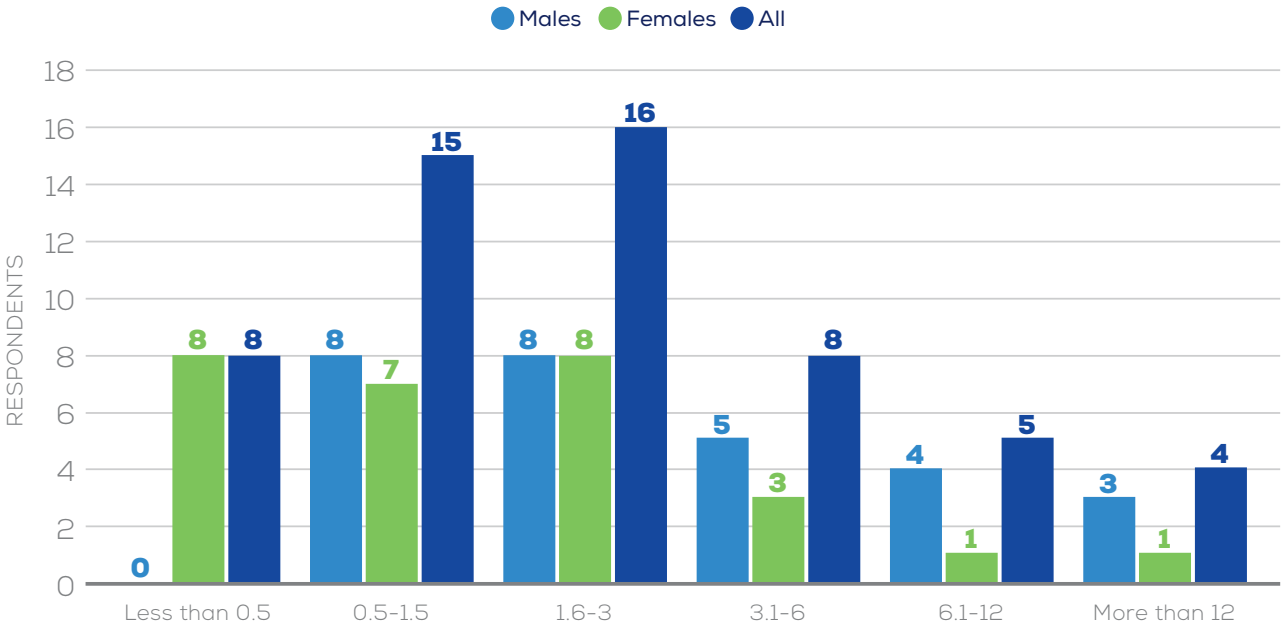
**TABLE 1. DESCRIPTION OF FARM PLOT SIZE (N=56)**

| DESCRIPTION | HECTARES |
|---|---|
| **Mean** | 5.9 |
| **Median** | 1.6 |
| **Standard Deviation** | 16.8 |
| **Minimum** | 0.4 |
| **Maximum** | 120 |

Although the questionnaire was designed to collect land size in hectares, fieldwork revealed that farmers knew or preferred to tell the size of their farm plots in terms of acres. Ninety-eight percent of respondents referred to acres, while only one use hectares. Another respondent refused to disclose his land size, apparently because it was too big. The data was then converted – one acre equals approximately 0.4 hectares.

Table 1 above shows a statistical description of samples in terms of their farm plot size. The average land size ownership among respondents was 5.9 hectares. This is more than twice the national average of 2.5 hectares due to a huge disparity in farmland ownership among respondents, which can also be observed from the range (119.6 hectares). The maximum farm size recorded was 120 hectares (300 acres), and the minimum was 0.4 hectare (one acre). The median of the land size held was much less than the mean, at only 1.6 hectares.

**FIGURE 3. FARM PLOT SIZE OF RESPONDENTS (N=56)**



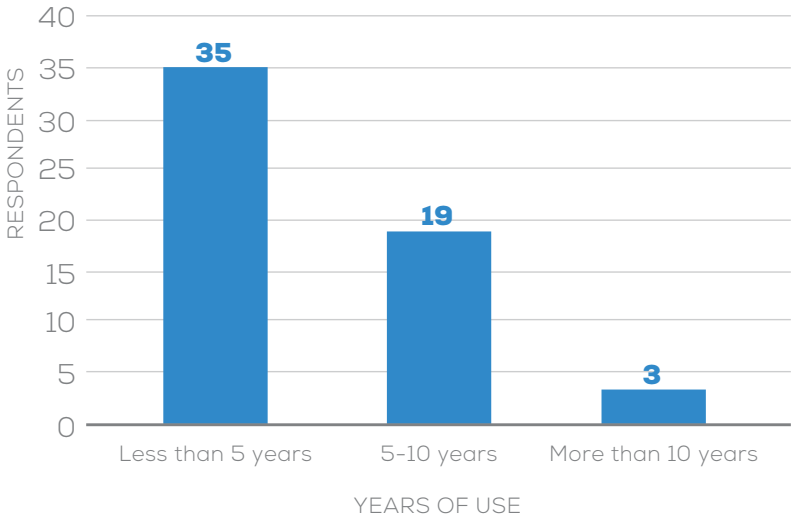

A big difference in farmland size was observed during the fieldwork. Plot size among respondents ranged from 0.4 to 120 hectares. Overall, 16 respondents owned farm plots ranging from 1.6 to 3 hectares followed by those (15 of 56 respondents) whose farm size was 0.5 to 1.5 hectares. Four respondents had farm plots of more than 12 hectares (Figure 3). All respondents confirmed they had full ownership of their lands. When asked if they also were renting any land and how much they pay for it, nine percent (5 out of 56) said they rented land for UGX 450,000 to 2,250,000 per hectare per year. All monetary figures are in Ugandan Shillings (UGX); as of October 15, 2019, USD $1 ~ UGX 3,701.

There is a huge gap in farm size ownership between male and female respondents. Women seemed to own smaller size farms than men (Figure 3). All (8 of 8) of interviewees who owned farm plots of less than 0.5 hectares were women. Only one woman out of four respondents had a farm more than 12 hectares. While the number of men and women was equal in farm size ranging from 0.5 to 3 hectares, the number of women steadily declined as plot size increased beyond 3 hectares and rose as the size decreased below 0.5 hectares.

## Farmer's experience with innovation

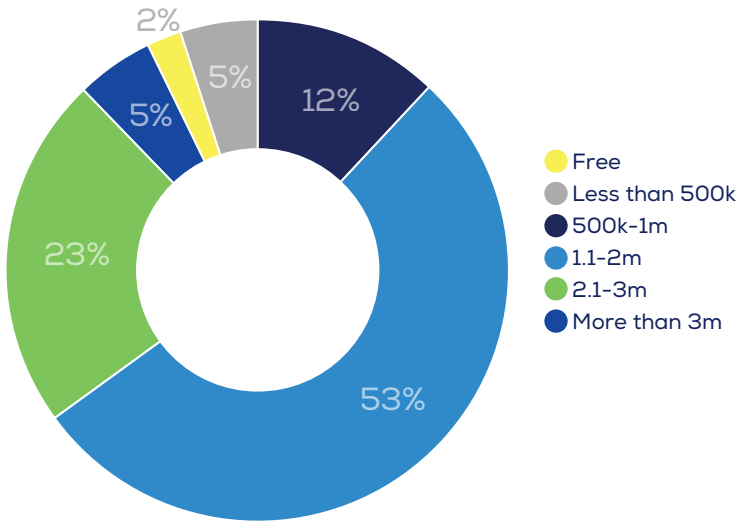
Interviewees were asked how long they had used their biogas systems. Their experience with the technology ranged from only two months to 11 years. One interviewee claimed to be the first to introduce and use the biogas technology in the entire district.

**FIGURE 4. FARMER'S EXPERIENCE WITH INNOVATION (N=57)**



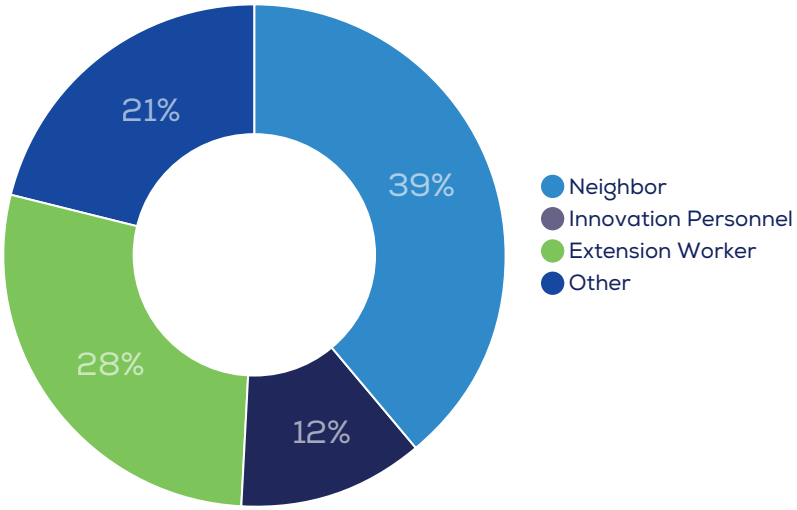

While biogas technology has been in Uganda since the 1950s, the Slurry-Separation System is a relatively recent innovation. Green Heat started to distribute it to its clients in 2015. The majority of respondents (61 percent) have less than five years experience with biogas technology (Figure 4). Thirty-three percent had used it from five to 10 years. Only three percent (5 of 57) had a lot of experience (more than 10 years) with biogas systems. The most biogas experienced farmers (three) had their systems for more than 11 years while the least experienced farmer (one) had it just over two months.

**FIGURE 5. SPENDING ON EQUIPMENT DUE TO INNOVATION (N=57)**



Users were asked how much they spent on equipment as a result of the innovation. One farmer said he got it free as a donation. Five percent (7 of 57) said equipment cost them UGX 500,000 to 1 million, and most said the costs were shared with the innovator or other donors. Expenses on innovation equipment for the majority (30 of 57) ranged from UGX 1.1 million to 2 million. Twenty-three percent (13 of 57) said they spent UGX 2.1 million to 3 million. The remaining three respondents spent over UGX 3 million. The minimum spending, apart from the one who did not pay, was UGX 200,000 to install a mechanical mixer, while the maximum paid was UGX 3.8 million (1.8 million for digester and 2 million for toilet installations) (Figure 5).

**FIGURE 6. HOW RESPONDENTS HEARD ABOUT THE INNOVATION (N=57)**

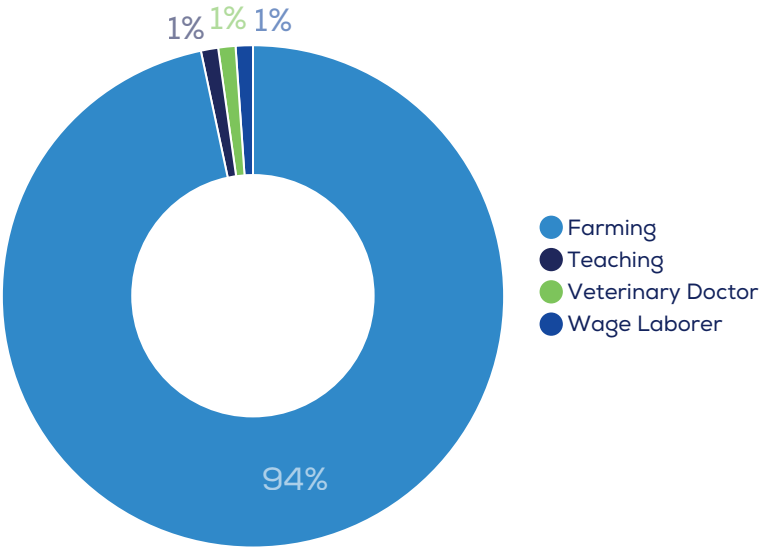



Respondents were asked how they originally learned about the biogas technology. They mentioned neighbors, innovation personnel, extension workers, and other sources. The majority (39 percent) said they learned from their neighbors, and 28 percent (16 of 57) said extension workers provided the information. On the other hand, 21 percent cited innovation personnel as the source of innovation information. The remaining 12 percent (12 of 57) said they heard about the technology from other sources, such as workshops, training, associations, and NGOs (Figure 6).

## Sources of income

Interviewees were asked to identify their primary sources of income (Figure 7).

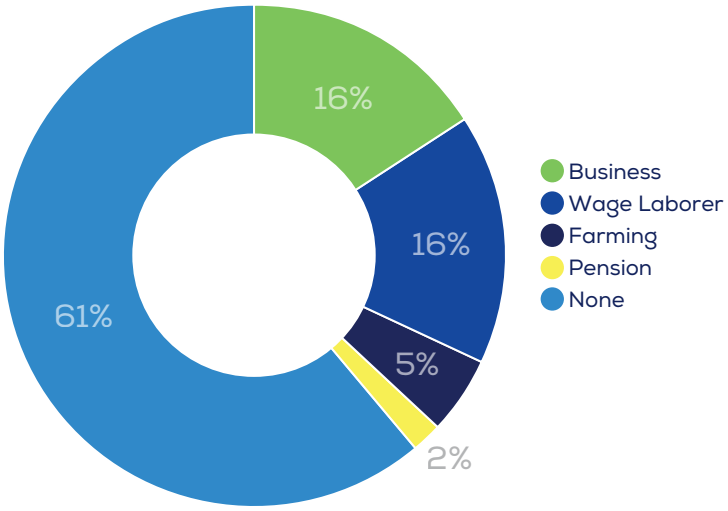
**FIGURE 7. PRIMARY SOURCE OF INCOME (N=57)**




Most respondents predominantly relied on agriculture for their livelihoods, with 94 percent saying farming was their primary source of income. According to the interviewees and field observation, major crops grown across all regions are banana (locally known as matooke), coffee, corn, fruits, and vegetables. Dairy, poultry, pig, and fish farming are practiced to some extent. Only three (six percent) had primary income sources other than farming, including teaching, veterinary doctor, and wage laborer (Figure 7).

They also were asked if they had sources of income other than their primary sources (Figure 8).

**FIGURE 8. ADDITIONAL SOURCE OF INCOME (N=57)**




Sixty-one percent (35 of 57) said they had no source of income other than farming. Doing business was a secondary source of income for 16 percent. Some of the business activities included street catering, drug shop, public transport, school services, and rentals. Similarly, 16 percent generated additional income from wage laboring, such as building, tailoring, and the like. Only three (five percent) confirmed that farming was their secondary source of income. Two percent said they were on pension.

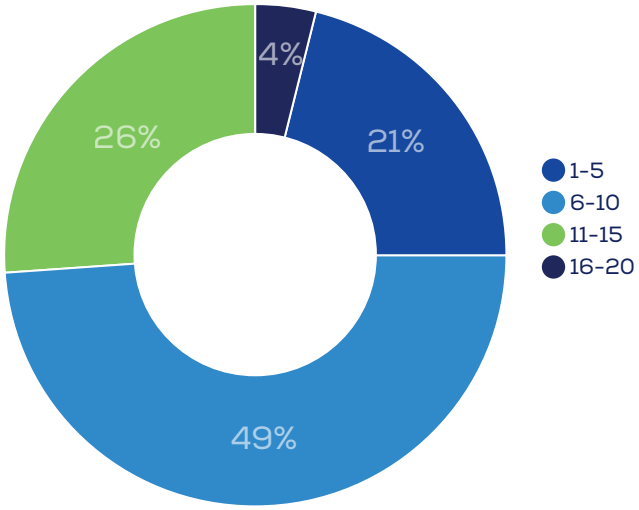
## Family size

**TABLE 2. STATISTICAL ANALYSIS OF FAMILY SIZE (N=57)**

| DESCRIPTION | # OF PEOPLE |
|---|---|
| Mean | 9 |
| Median | 8 |
| Sample Variance | 14 |
| Range | 18 |
| Minimum | 2 |
| Maximum | 20 |

A total of 496 family members were represented within the 57 interviewed households. The mean and median family size were nine and eight members, respectively. This is far larger than the national average household size of 4.7 members. The minimum family size recorded was only two members, and the maximum was 20 members (Table 2).

**FIGURE 9. FAMILY SIZE OF RESPONDENTS (N=57)**




The highest number of sample households (49 percent) had six to 10 family members. Households with a family size of 11 to 15 members accounted for 26 percent. Twenty-one percent had one to five family members. The remaining four percent (2 of 57) of households had 16 to 20 members (Figure 9).

# METHODOLOGY

## Sample Selection

Although Green Heat also has customers in the neighboring countries of Ethiopia, Rwanda, and Togo, only customers in Uganda were targeted for this study.

**TABLE 3. DISTRIBUTION OF TOTAL CLIENTS IN UGANDA**

| REGIONS | HOUSEHOLDS | | INSTITUTIONS | | |
|---|---|---|---|---|---|
| | MALE | FEMALE | SCHOOL/ COLLEGE | CHURCH | CHARITY |
| **Central** | 204 | 199 | 7 | 1 | 1 |
| **Eastern** | 179 | 104 | 3 | 0 | 0 |
| **Northern** | 112 | 112 | 3 | | |
| **Western** | 115 | 152 | 5 | 1 | 0 |
| **Total** | 610 | 567 | 18 | 2 | 1 |

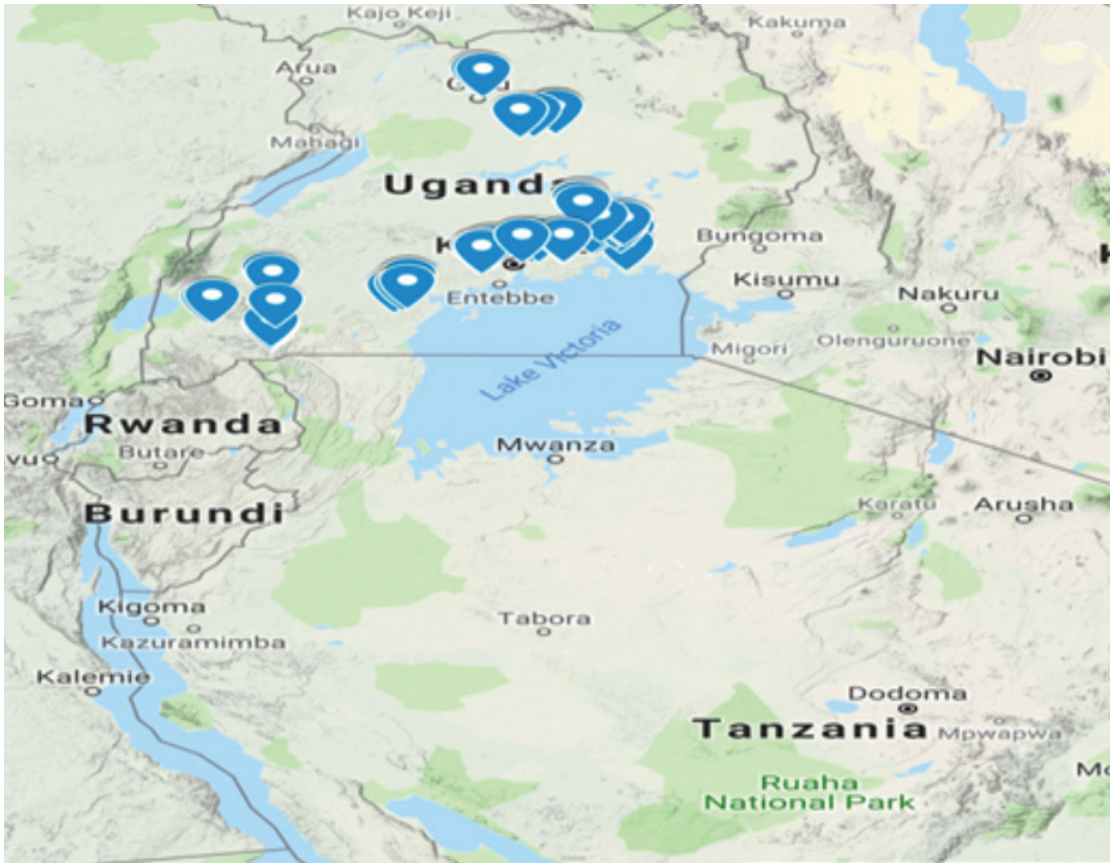
The total list of customers provided by Green Heat and SWFF included 1,177 (567 females) households and 21 institutions. Since the project's demand was to interview a minimum of 50 individual households, institutions were excluded from the sampling process. Households then were grouped into regions. Accordingly, the customers were: 403 (199 females) from Central; 283 (104 females) from Eastern; 224 (112 females) from Northern; and, 267 (152 females) from Western regions (Table 3).

**TABLE 4. DISTRIBUTION OF SAMPLE RESPONDENTS (N=57)**

| REGIONS | DISTRICT | MALE | FEMALE |
|---|---|---|---|
| **Central** | Buikwe | 3 | 1 |
| | Gomba | 4 | 2 |
| | Masaka | 4 | 3 |
| | Mukono | 0 | 3 |
| **Eastern** | Budaka | 3 | 3 |
| | Jinjia | 2 | 2 |
| | Kamuli | 4 | |
| **Northern** | Gulu | 0 | 3 |
| | Kole | 2 | |
| | Lira | 1 | 5 |
| **Western** | Bushenyi | 1 | 3 |
| | Mbarara | 2 | 0 |
| | Isingiro | 3 | 3 |
| | **Total** | **29** | **28** |

Taking time, financial constraints, and scattered locations of end-users into consideration, the sample size was set at 60 individual households. This, in turn, was proportionally allocated into the regions. A total of 13 districts (four from the Central region and three each from the other regions) was randomly selected. The districts surveyed included Buikwe, Gomba, Masaka, and Mukono from Central; Budaka, Jinjia, and Kamuli from Eastern; Gulu, Kole, and Lira from Northern; and, Bushenyi, Mbarara, and Isingiro from the Western region. Twenty-one (10 females), fourteen (5 females), eleven (9 females), fourteen (7 females) respondents were randomly selected from the Central, Eastern, Northern, and Western regions, respectively (Table 4). However, the interview was successful with 57 (28 females) respondents since three were not available in their homes or farm fields during the visit. More samples, both districts and respondents, were taken from the Central region because it had more end-users distributed across several districts compared to the other regions.

**FIGURE 10. LOCATION MAP OF SAMPLE RESPONDENTS**




Green Heat staff, based on advice from the Ugandan Ministry of Health, recommended avoiding districts that are close to neighboring countries of the Republic of Congo and the Republic South Sudan, which are Ebola prone areas. The recommendation was followed, and districts located 100 to 150 kilometers from both borders were deliberately excluded from the randomization process.

All respondents were interviewed in person in their homes or farm fields. The questionnaire was developed and provided by SWFF. The language barrier was not a serious issue, as Uganda is a predominantly English-speaking nation. As such, the interview sessions mostly were conducted in English, although some were done in local dialects through the help of local interpreters.

## Limitations

Respondents were happy to receive the interviewers as visitors and were excited to talk about their biogas plants for three main reasons. First, it is considered very generous of local communities to host visitors. Rural people in Uganda have a culture of providing a "Visitor's Book" for visitors to fill in their name, address, contacts, reason for the visit, and comments. The record is kept for generations and is considered prestigious. Secondly, Green Heat customers were very happy to own biogas and with the countless benefits they make out of their systems. The plant is not only considered as a point of pride that needs to be visited, but also used as an opportunity to tell how great the technology is and how much their lives have changed since using it. Many said they did not have enough words to list all the advantages. Finally, but equally as important, others wanted to use the opportunity to tell about the challenges they have faced with their systems. They wanted to be heard and hoped their systems would get fixed afterward.

However, the questionnaire had numerous limitations. Many of the questions were too long, too quantitative, and too complicated for farmers. They demanded respondents' literacy and a lot of their time. Consequently, some questions remained unanswered, took a long time to get answered, or led to several estimated or inaccurate answers. Some respondents left in the middle of the interview due to the time required to complete it. There were inconsistencies of data because at times data that was intended to be quantitative was provided qualitatively. A few respondents were hesitant about responding to some questions, especially in relation to income and land size. Others did not know how big their land might be in terms of specific units or how much income they make annually. Lastly, some target respondents were absent in their homes and farm fields.

# RESULTS

# EXPERIENCE WITH THE INNOVATION

Respondents were asked to list the main benefits of biogas innovation. Each respondent gave more than one and heterogeneous answers (Table 5).

**TABLE 5. PERCEIVED BENEFITS FROM BIOGAS TECHNOLOGY (N=57)**

| BENEFITS | FREQUENCY | % |
|---|---|---|
| **Energy** | 57 | 100 |
| **Fertilizer** | 51 | 89 |
| **Hygiene** | 13 | 23 |
| **Environmental sustainability** | 7 | 12 |
| **Animal feed** | 5 | 9 |
| **Source of additional income** | 4 | 7 |

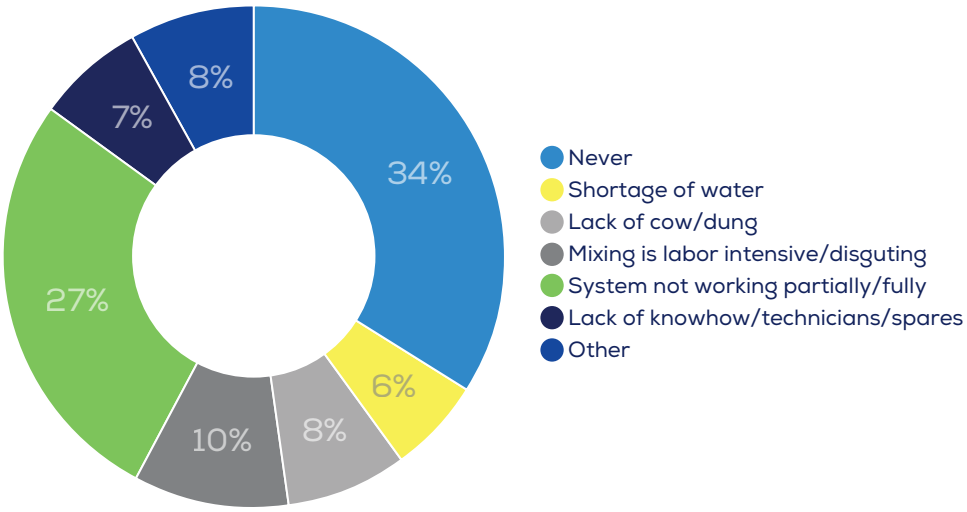
All respondents perceived energy supply as the main benefit of biogas technology. They said biogas provides clean and inflammable energy mainly for cooking and lighting purposes.

Providing fertilizer was the second most frequently mentioned benefit. While biogas is used to produce energy, the large potential of bio-slurry often has been overlooked. However, 89 percent of the respondents in this study said biodigesters had been providing organic fertilizers that are rich in nitrogen and phosphorous and helped them increase crop productivity and improve survival rates.

Hygiene or sanitation was the other benefit of biodigesters, with 23 percent (13 of 57) citing this advantage. They expressed the hygienic effect of biogas plants in two ways: (a) there is no more messy cow dung or other organic waste in their compounds as it is directly fed to the system; and, (b)

there is no more indoor pollution from  smoky kitchens using firewood or charcoal because it has been replaced with clean methane gas. Twelve percent said that biogas also helps maintain environmental sustainability. This mainly is in relation to less firewood and charcoal consumption for energy purposes, which means a reduced rate of deforestation, and to the organic and environmentally friendly nature of the slurry fertilizer they apply to their farm fields. Five respondents said they also used the slurry to feed their animals – pigs, poultry, and fish. Another benefit was the fact that biogas could become a source of additional income. They said the demand for bio-slurry is very high and not everyone has access to the innovation. Therefore, some (4 of 57) were able to generate additional income by selling surplus slurry to neighbors and friends.

**FIGURE 11. CHALLENGES FACED WHILE USING INNOVATION (N=57)**




Clients were asked if they had experienced any challenges while using the biogas innovation. They expressed several problems (Figure 11). The majority (34 percent) said they never had any problems associated with their systems. However, 27 percent said their systems had not worked fully or partially. Eight percent said the lack of cow dung was their major challenge. Six percent mentioned a shortage of water. Lack of technical knowhow and spares were mentioned by seven percent. Eight percent mentioned other challenges, such as the long distance between the biogas plant and the dairy farm or crop field. Another challenge mentioned by 10 percent of farmers interviewed was difficulty in mixing cow dung. They said manually mixing dung, which is the case for many of the clients, is tiresome and, at times, disgusting – especially with pig dung.

In a separate question, farmers were asked if there had been any negative impact caused by the innovation in their respective communities. The majority of the respondents said there was no negative impact whatsoever. Only two respondents mentioned that there were some jealous individuals who spread bad rumors about the technology.


*Gender-Based Training on Fertilizer Application.*

# BENEFITS OF INNOVATION

## Agricultural activities benefits

Sample farmers were asked if the biogas innovation made them change their farming practice and how (Table 6).

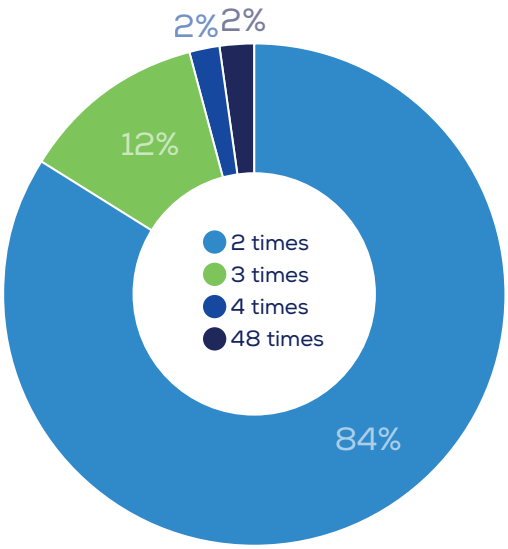
**TABLE 6. CHANGE IN FARMING PRACTICES DUE TO INNOVATION (N=56)**

| FARMING PRACTICE | FREQUENCY | % |
|---|---|---|
| It helps me to decide which crops to plant | 40 | 70 |
| Introduced new crops | 27 | 47 |
| It helps me to decide when to plant | 45 | 79 |
| Changed irrigation system | 10 | 18 |
| Reduced water usage | 11 | 19 |
| Source of additional income | 4 | 7 |

The majority (70 percent) of respondents mentioned they were able to decide which crops to plant with the help of their biogas systems. Twenty-seven percent said the innovation made them introduce new crops. On the other hand, 79 percent confirmed their systems assisted in deciding when to plant their crops. Change of irrigation system was mentioned by 18 percent, and 19 percent said the innovation helped them reduce their water usage.

Farmers were asked how many times they harvest in a year (Figure 12).

**FIGURE 12. NUMBER OF HARVEST A YEAR (N=57)**

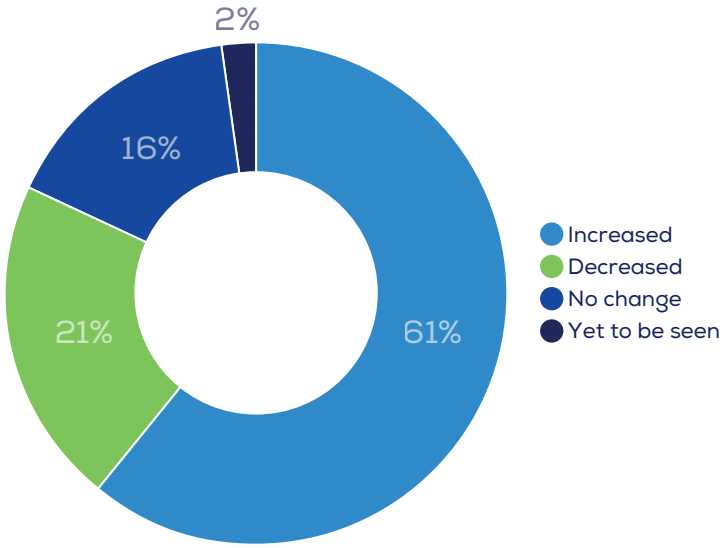


While the majority (84 percent) harvest two times per year, 12 percent harvest three times. Two percent said they harvest four times annually, and only one said he harvests every single week.

## Water benefits

Reducing water consumption by biodigesters, and hence increasing users' access to water, was the main benefit expected of Green Heat's intervention, particularly the introduction of SST. Based on this, end users were asked how much their access to water and/or water consumption had changed (Figure 13).

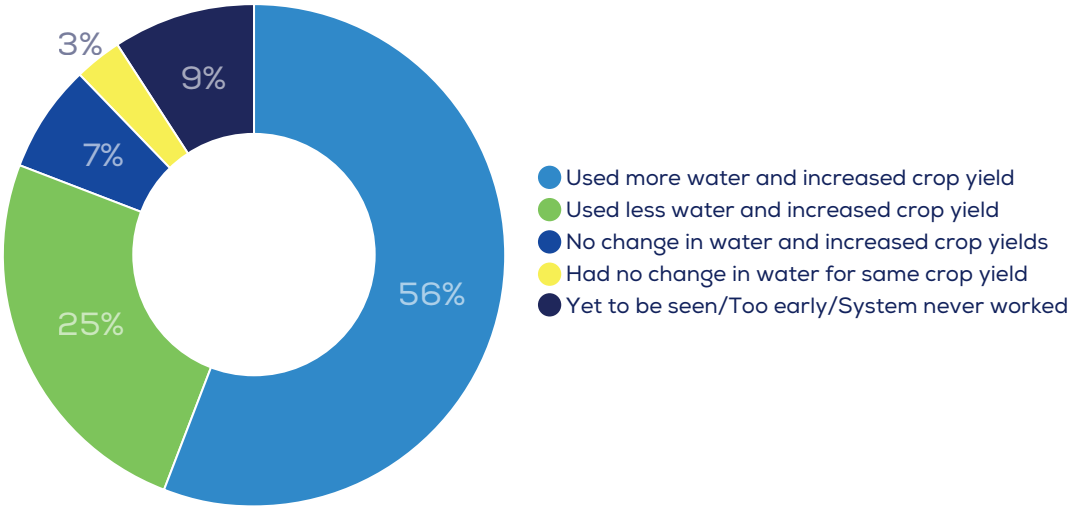
**FIGURE 13. CHANGE IN WATER CONSUMPTION SINCE INNOVATION (N=57)**



Although they could not state it quantitatively, they were able to qualitatively articulate the changes as increased, decreased, no change, or yet to be seen (Figure 13). Of respondents, 61 percent (35 of 57) said the innovation made them consume more water mainly due to cow dung mixing. Twenty-one percent (12 of 57) said their biogas plants helped them decrease the amount of water usage. Respondents believe the improvement was due to the use of biogas byproduct to water crops; slurry fertilizer shortens the growing season, and fertile soil preserves water. Sixteen percent (9 of 57) said their water consumption was unchanged, including two who had not used the system since it was installed. One respondent said the impact is yet to be seen as the system had only been installed for two months.

Furthermore, the study attempted to find out if the innovation had any impact in terms of water consumption as opposed to crop yield.

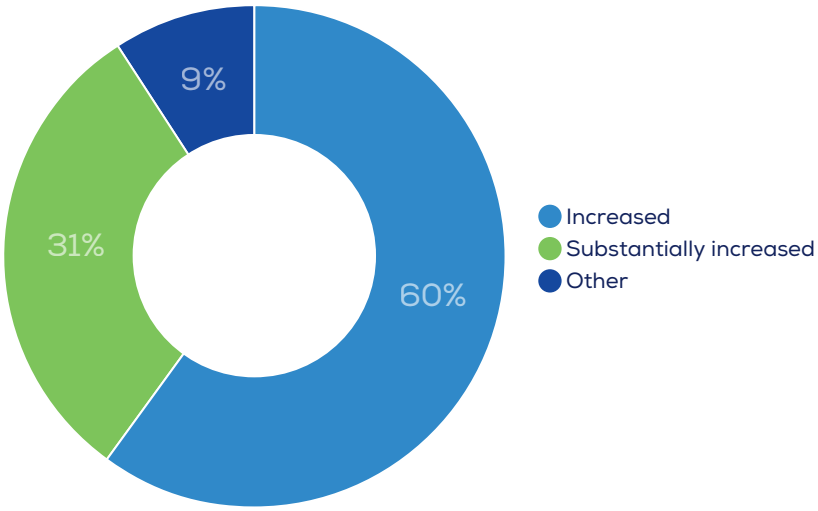
**FIGURE 14. WATER USAGE VERSUS CROP YIELD DUE TO INNOVATION (N=57)**




Fifty-six percent of respondents said they used more water as a result of the innovation but their crop yield also increased. On the other hand, 25 percent said their biogas technology made them consume less water to get more crop yield. Seven percent said their biogas had no impact on water consumption but helped them increase crop yields. The innovation seemed to have no impact on water consumption or crop yield for three percent of the respondents. The remaining nine percent said their systems never worked or it was too early to see results (Figure 14).

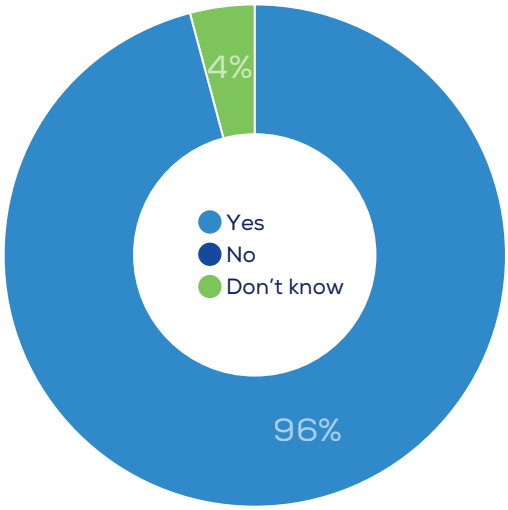
## Crop benefits

**FIGURE 15. CHANGES IN CROP YIELDS AFTER BIOGAS**




Among interviewees, 60 percent reported their crop yield increased due to biogas, and 31 percent said the biogas helped them to substantially increase their crops. Only nine percent did not know the impact of the innovation on their crop yield because their systems never worked or were recently installed.

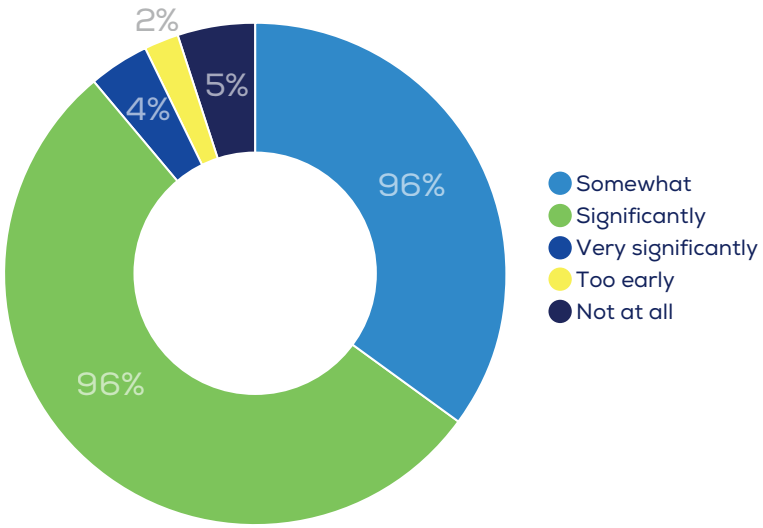
**FIGURE 16. IMPROVEMENT IN CROP SURVIVAL RATE DUE TO BIOGAS (N=57)**




Respondents also were asked if the innovation had any impact on crops' survival rate. Ninety-six percent said their crops' survival rate improved due to the use of biogas technology. Four percent said they couldn't figure it out because their system was either not working or just introduced.

## Income benefits

**FIGURE 17. FAMILY INCOME IMPROVEMENT DUE TO INNOVATION**




When asked if their family income improved after they started to use biogas, 54 percent said income improved very significantly. Thirty-five percent said their household income significantly increased due to the use of biogas. Family income somewhat improved for five percent. While no change was observed in the income of five percent of the interviewees, it was too early for four percent of the sample to evaluate (Figure 17).

## TABLE 7. COMPARISON OF SEASONAL CONSUMPTION OF INPUTS AND EXPENSES

| CONSUMPTION OF FERTILIZER AND EXPENSES (N=44) | | | | |
|---|---|---|---|---|
| | BEFORE INNOVATION | | AFTER INNOVATION | |
| | FERTILIZER (KG) | COST (UGX) | FERTILIZER (KG) | COST (UGX) |
| Total | 1,336 | 2,244,500 | 65 | 190,000 |
| Average | 30 | 51,011 | 1 | 4,318 |
| Median | 0 | 0 | 0 | 0 |
| Minimum | 0 | 0 | 0 | 0 |
| Maximum | 300 | 780,000 | 50 | 150,000 |

| CONSUMPTION OF PESTICIDES AND EXPENSES (N=46) | | | | |
|---|---|---|---|---|
| | BEFORE INNOVATION | | AFTER INNOVATION | |
| | PESTICIDES (KG) | COST (UGX) | PESTICIDES (KG) | COST (UGX) |
| Total | 84 | 1,409,000 | 39 | 798,500 |
| Average | 2 | 30,630 | 1 | 17,359 |
| Median | 1 | 11,000 | 0 | 0 |
| Minimum | 0 | 0 | 0 | 0 |
| Maximum | 20 | 320,000 | 10 | 190,000 |

| CONSUMPTION OF HERBICIDES AND EXPENSES (N=45) | | | | |
|---|---|---|---|---|
| | BEFORE INNOVATION | | AFTER INNOVATION | |
| | HERBICIDES (L) | COST (UGX) | HERBICIDES (L) | COST (UGX) |
| Total | 65 | 1,015,500 | 64 | 962,000 |
| Average | 1 | 22,567 | 1 | 21,378 |
| Median | 0 | 2,500 | 0 | 0 |
| Minimum | 0 | 0 | 0 | 0 |
| Maximum | 20 | 300,000 | 20 | 300,000 |

| CONSUMPTION OF ENERGY AND EXPENSES (N=40) | | | | |
|---|---|---|---|---|
| | BEFORE INNOVATION | | AFTER INNOVATION | |
| | CHARCOAL/ FIREWOOD (KG) | COST (UGX) | CHARCOAL/ FIREWOOD (KG) | COST (UGX) |
| Total | 414,701 | 51,661,547 | 20,583 | 11,578,373 |
| Average | 10,368 | 1,291,539 | 515 | 289,459 |
| Median | 473 | 120,000 | 82 | 24,600 |
| Minimum | 0 | 0 | 0 | 0 |
| Maximum | 150,000 | 37,500,000 | 15,000 | 6,750,000 |

Data for seasonal agricultural inputs consumption as well as associated costs incurred by respondents was recorded during the survey. Although some of the farmers did not provide specific figures, the majority was able to quantify their fertilizer, pesticides, herbicides, and charcoal and/ or firewood consumption trends before and after using the innovation. Everyone that responded

was counted, even if they did not use the input/s. Of the 57 interviewees, patterns for fertilizer consumption were shared by 44, pesticide consumption by 46, herbicides consumption by 45, and energy consumption by 40. However, numerous estimations and conversions were carried out as respondents provided data in a wide range of units. For instance, some farmers quantified their fertilizer usage in terms of number of sacks, and charcoal/firewood in terms number of trucks or sacks. Therefore, the information may not be accurate or representative enough.

Accordingly, the total amount of fertilizer consumed in a season was 1,336 kilograms at a cost of UGX 2,244,500 before the innovation. After using the innovation, it reduced to 65 kilograms at a cost of UGX 190,000, less by 1,271 kilograms and UGX 2,054,500. This is because only three respondents continued to use inorganic fertilizer while others completely relied on the slurry byproduct after the innovation. Similarly, the consumption of pesticides was reduced due to the innovation. The total amount of pesticides consumed was 84 and 39 kilograms before and after the innovation, respectively. The average cost incurred was UGX 30,630 and 17,359 before and after the innovation, respectively. For herbicides consumption, the amount used in a season was equivalent before and after innovation – 65 and 64 liters, respectively. However, there was some difference in cost. The total cost of herbicides was UGX 1,015,500 before biogas, but after the use of biogas it was UGX 962,000 (less by UGX 53,500). Respondents said there are many options now and the price is cheaper. The biggest change was observed in energy consumption patterns of users. Forty respondents consumed a total of 414,701 kilograms of charcoal and/or firewood in a season before biogas. After the introduction of biogas, their total charcoal and/or firewood usage reduced to 20,583 kilograms. This is less by 394,118 kilograms (1,915%). Furthermore, the average seasonal charcoal and/or firewood expenses of the users decreased from UGX 1,291,539 to UGX 289,459 (Table 7).

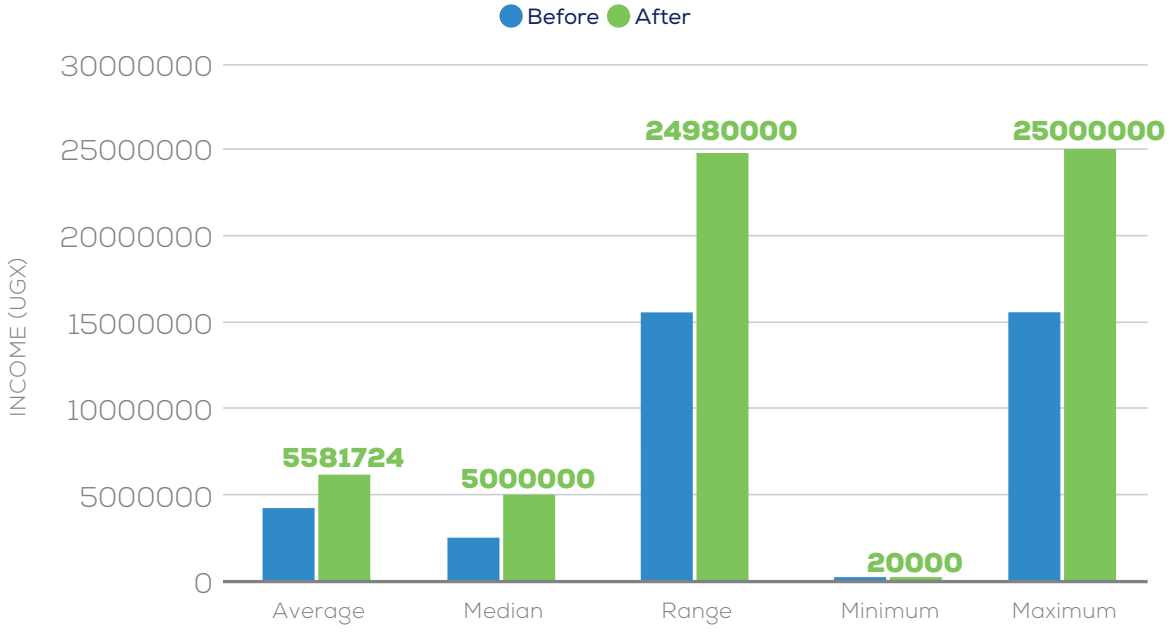
**TABLE 8. HARVEST AND SELL OF CROPS BY FARMERS**

| | BANANA | MILLET | COFFEE | SORGHUM | VEGETABLES | CORN | BEANS | RICE |
|---|---|---|---|---|---|---|---|---|
| Number of Respondents | 11 | 1 | 10 | 2 | 6 | 14 | 8 | 1 |
| Total harvested (Kg) | 152,900 | 10,000 | 47,110 | 20,500 | 21,550 | 10,120 | 8,110 | 400 |
| Average | 13,900 | 10,000 | 5,223 | 10,250 | 4,310 | 778 | 1,802 | 400 |
| Median | 600 | 10,000 | 800 | 10,250 | 800 | 600 | 1000 | 400 |
| Average price (UGX/kg) | 1,046 | 2,500 | 2,111 | 650 | 3,700 | 923 | 1,931 | 2,800 |

Farmers were asked what crops they harvested in the previous season and how much the crops were sold for. Bananas, coffee, corn, beans, and vegetables were the major crops harvested by many of them. The average yields of bananas, coffee, vegetables, corn, and beans harvested was 13,900, 5,223, 4,310,778 and 1,802 kilograms, respectively (Table 8). The average price for a kilogram of bananas was UGX 1,046 whereas the price for coffee was UGX 2,111. Corn and beans were sold for UGX 923 per kilogram and UGX 1,931 per kilogram on average.

## Poverty reduction benefits

**FIGURE 18. INCOME BEFORE AND AFTER INNOVATION (N=29)**



Respondents were asked to share their annual income before and after the innovation. Only 51 percent (29 of 57) were able to determine their income in quantitative terms. Others, although they could express it qualitatively (Figure 17), were unable to provide numerical data. The majority shared annual data while others gave seasonal data, which was then multiplied by the number of seasons to determine income per year. The average, median, range, and maximum income all were higher after the innovation than before (Figure 18). The median was 60 percent higher after the innovation. Whereas, the maximum income earned was UGX 16 million and UGX 25 million before and after the innovation, respectively.

**TABLE 9. WHAT DO FARMERS DO WITH THE NEW INCOME?**

| NEW INCOME SPENT ON | FREQUENCY | % |
|---|---|---|
| Send and/or keep children in school | 45 | 79 |
| On investment in farming | 37 | 65 |
| Improving house | 15 | 26 |
| Social functions such as weddings | 3 | 5 |
| Others | 6 | 11 |

Since the majority of sample households confirmed that biogas had enabled them to increase their household income, they were asked what they do with the new or additional income generated due to the innovation. Sending or keeping children in school was the most frequently mentioned use for the new income. The second most commonly mentioned purpose was on investments in farming. Improving their house was identified by 26 percent of the respondents. Three households mentioned they also spent it on social functions, such as weddings. For the remaining six households, it was either too early or their systems never worked so they had no new income, or they didn't answer (Table 9).

## Gender differences

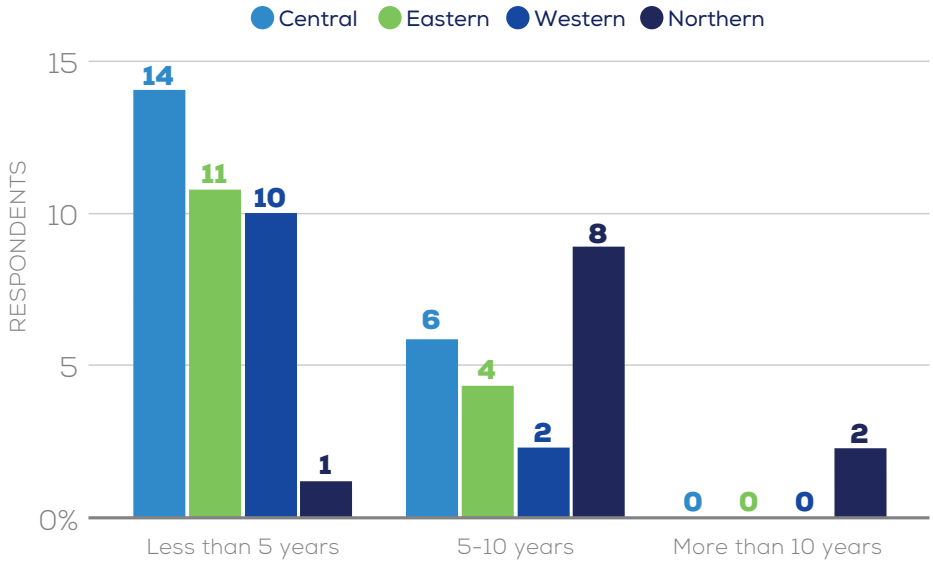
**TABLE 10. HOW HAS THIS INNOVATION HELPED YOU?**

| USAGE | MALES | % | FEMALES | % |
|---|---|---|---|---|
| Helps by lower cost of inputs | 13 | 45 | 12 | 43 |
| Helps women farmers as well as men | 13 | 45 | 20 | 71 |
| Reduces crop wastage | 2 | 7 | 0 | 0 |
| It helps me to decide when to plant | 14 | 48 | 9 | 32 |
| It helps me to decide which crops to plant | 5 | 17 | 7 | 25 |
| Improves the health and strength of livestock | 1 | 3 | 0 | 0 |
| Increases my yield through timely forecasts | 13 | 45 | 13 | 46 |
| They made a special effort to include women farmers | 1 | 3 | 4 | 14 |
| Helps in producing more of our most important crop | 6 | 21 | 9 | 32 |
| Makes Water Reusable | 1 | 3 | 3 | 11 |
| Helps reduce labor | 2 | 7 | 1 | 4 |

Any difference in gender in terms of how has the technology helped end users was explored. The most frequently mentioned benefit by male respondents (48 percent) was helping to decide when to plant crops. However, most female respondents (71 percent) stated helping women farmers as well as men as a benefit of the innovation. Forty-five percent of males and 43 percent of females said biogas helps lower the cost of inputs. Increasing crop yield through timely forecast was the second most mentioned benefit by both males (45 percent) and females (46 percent). The least frequently mentioned benefits by males were making water reusable, making a special effort to include women farmers, and improving the health of livestock. No female mentioned the benefits of reducing crop wastage or improving the health of livestock (Table 10).

## Regional differences

**FIGURE 19. REGIONAL DIFFERENCE OF EXPERIENCE WITH INNOVATION**




Clients from the Northern region of Uganda seemed to be more experienced than those from other regions. The two respondents who used biogas for more than 10 years were from the Northern region. Of the 36 respondents who used biogas for less than five years, 14 were from Central, 11 from Eastern, 10 from Western, and one from Northern regions. The majority of those who had five to 10 years biogas experience were from Northern followed by those from Central (Figure 19).

# DISCUSSION

As the fieldwork started, there was some confusion from the field evaluator concerning whether the interviewees were the right targets/customers. While administering the question "how long have you been using the innovation" in the questionnaire, some respondents answered as having used it for eight to 11 years. Meanwhile, the list of clients provided by both Green Heat and SWFF showed that the earliest SST was installed in 2015, meaning four years maximum usage. With this unexpected heterogeneity in mind, Green Heat personnel were contacted and confirmed that many of the customers had used biodigesters for a long time and SST was installed onto their existing systems. Despite this information, it was still not fully clear, whether to only focus on SST or the entire system. Fortunately, a field "Check-in Call" was set up by SWFF for this type of inquiry. It was confirmed by SWFF that the interest was to study the impact of the entire biogas systems equipped with SST on clients' livelihoods.

## Usage/Availability

Of the interviewed farmers, 34 percent have used their biogas systems properly and never had problems. Others, however, revealed that their systems had not worked fully or worked partially for various reasons. Two respondents said their biogas plants never worked since they were installed, and the owners believed that lack of professionalism of those who built it was the reason. In one village in Northern Uganda, respondents said only four of the 20 systems installed in that village were functioning at the time of the interview visit. It also was observed that many lighting units were not in service although the systems were still running.

The partial or complete failures of biogas plants were in association with several other factors as well. Eight percent of respondents said lack of cow dung had been their major challenge. They said their cows died or were stolen, and they no longer had access to dung to feed to their systems. Several farmers collected cow dung from neighbors to keep their systems running. Another challenge mentioned by 56 percent of respondents was the shortage of water. A majority of the farmers said their biogas plants made them consume more water due to mixing, and they did not use recycled water to mix the dung. Non-functioning systems due to lack of cow dung or water were observed. Lack of technical knowhow and spares were mentioned as a challenge which directly or indirectly caused the failure of many systems. Respondents said they did not have the expertise to fix defects in their innovations regardless of the seriousness of the failures nor did they know who to contact for spares, where to get spares, or to address any issue pertaining to their biodigesters. During the survey, it was witnessed that many of the faults required only basic spares and technical knowhow as the interpreters/guides were able to fix some issues during the field visit without using any spares or special tools. As a result, those respondents who had their problems solved by the interpreters/guides were thankful they were part of the field team.

*Systems out of service*

## Crop yield/survival

The majority of respondents reported positive impacts of the biogas innovation on yield and survival of rates of crops. Ninety-six percent confirmed improvements in the survival rate of their crops due to biogas technology. Sixty percent said although they had to consume more water to run the innovation, their crop yield increased as a result. Thirty-one percent said the biogas helped them to substantially increase their crop yields. Users mentioned that the fertilizing effect of the slurry is very high and organic. During the field survey, it was learned that a farmer was about to launch a local association named "Buyernga Bamalakulabako Farmers Group." The association aims at producing and packaging high-quality slurry (both liquid and solid) to the market. The farmer claimed their bio-slurry concentrate would contain 20 percent cow dung, 30 percent nitrogen, five percent phosphorus, five percent potassium, and 40 percent water. He said it can increase crop yield by as much as 200 percent. Although this is a little less than the 270 percent increase in crop yields set by Green Heat, one can easily imagine how effective the bio-slurry can be in increasing crop productivity and survival rates.

Through the anaerobic reaction that takes place in the digestion chamber, the methane gas, which would otherwise burn crops if cow dung was directly applied to the farm fields, gets separated. Moreover, the same process decontaminates the slurry from any potential pests that would be

*Beans intercropped with bananas*

caused if raw cow dung was used as fertilizer. Some farmers mix the liquid component of the bio-slurry with local ingredients and use it as pesticides. The bio-slurry helped users to not only choose when to plant and which crops to plant, but also reduce their agricultural inputs consumption such as inorganic fertilizers, pesticides, and herbicides. This means farmers no longer need to buy such inputs or can use them to a much lesser extent. It is to be recalled that 70 percent of the interviewees were able to decide which crops to plant, and 79 percent were able to decide when to plant their crops due to biogas. Farmers also were able to introduce new farming techniques, such as intercropping, due to the use of slurry. One farmer who had his biogas system connected to the toilet said that he also was able to get additional crops on his farm plot pollinated from human waste.

## Changes in income

An increased income was reported by 89 percent of the interviewees due to the use of biogas, of whom 54 percent reported a very significant improvement in their household income. Five percent said family income improved somewhat. Households' average annual income after the innovation was UGX 5,581,724, up by 32 percent as compared to the average income before of UGX 3,787,302. Respondents said not only had the innovation helped them boost their crop productivity but also had reduced costs on inputs such as fertilizer, herbicides, and pesticides.

Clients reported using their new income from the innovation for various purposes. The additional income was used by the majority to send or keep their children in school. Sixty-five percent reinvested it in their farming business, and 26 percent reported using it for improving their houses.

Five percent of target farmers could not report any additional income, as it was too soon after getting the innovation. The remaining two percent said they never saw any improvement in their family income from the innovation because their systems never worked since being installed.

The interviewees also reported several other non-income benefits from the biogas, such as increasing the value of land which, in turn, improves their access to credit schemes. The innovation also helped farmers reduce the usage of agricultural inputs, such as inorganic fertilizer which, in turn, reduces cost and enhances savings. Moreover, biogas has become a source of additional income for many of the clients interviewed. The slurry byproduct was used as fertilizer, to feed animals, and as a product for sale. Blended with maize grains, it was used to feed animals, particularly pigs, poultry, and fish. A woman from Lira, in Northern Uganda, said: "If you feed bio-slurry to a chicken, it can gain 2.5 killogram in weight in just three months and be ready for sale." Due to the limited or no negative environmental impact coupled with a high fertility effect, there is high demand for bio-slurry among farmers. Since not everyone owns the biogas innovation, some users were able to generate additional income by selling surplus slurry to others.

*Cow on an SST Biodigester Farm (left). Bio-slurry for sale @ UGX 40,000/Barrel (right).*

## Gender differences

Overall, no major difference was observed between genders relative to the innovation. However, when asked to prioritize the benefits of biogas for farming activities, the innovation's contribution toward enabling decisions on when to plant was the most frequently chosen benefit by male respondents (48 percent). Among females, however, the fact that biogas helps both male and female farmers was mentioned by the majority (71 percent). Lowering the cost of inputs and helping both female and male farmers were similarly chosen by 45 percent of male respondents. For 46 percent and 43 percent of female respondents, increasing crop yield through timely forecasts and lowering the cost of inputs were prioritized, respectively (Table 6).

## Affordability

Due to the high cost of installation, respondents said, "Not everyone can afford biogas." They indicated many of their friends and neighbors would like to adopt it if not for the high cost of equipment or lack of a cow. Cow ownership is an essential requirement for biogas adoption but the price of a cow is unaffordable to many rural farmers. Another affordability challenge mentioned by farmers was the large space required to install a biogas plant. Respondents indicated that lack of space was why some of their peers were unable to introduce the innovation. Interestingly, one farmer suggested if the biogas components (from mixing chamber to the outlet) could be arranged somehow vertically instead of laying them horizontally, people with small land size could use it.

Data on overall expenses spent on biogas systems was recorded during the survey. Although one respondent received it as a donation, the cost of equipment ranged from UGX 200,000 to 4 million, the minimum being only maintenance cost covered by the farmer. Some farmers got their systems in a cost-sharing mode between themselves and the innovator or other NGOs. Some respondents reported that they also were supported with cows.

Two types of bio-digesters were observed during the fieldwork – Fixed Dome and Flexible Balloon options (Photo 5).

*Fixed Dome type (left). Flexible Balloon type (right).*

While the ultimate purpose remains the same in both options, they significantly vary in cost of installment and maintenance. These two options not only vary in cost but also in the space they require. The Fixed Dome occupies a larger space than the Flexible Balloon Option. Fixed Dome is a sub-surface digester that ranges from four to 50 cubic meters and is also known for offering long-term solutions for effective waste management. The majority of systems visited were of this nature. The Balloon Option is a portable digester that is quicker and easier to install and is best suited for small farms and households. The plastic casing is fed with organic waste and expands as gas is produced. The Balloon Option is relatively cheaper and lays on a relatively smaller surface. This option, however, has not yet been widely used by farmers because it is a relatively newer technology. Only one respondent had this type of biogas system.

## Energy benefits

The principal benefit farmers would expect from biogas is energy generation. In this particular survey, 100 percent (57 of 57) mentioned the benefit of energy (Table 3). A woman from Jinjia in the Eastern region of Uganda said, "Because of biogas, our cooking task has become easier, faster, cleaner, and safer." It has enabled farmers to save time required for cooking and to have more time to engage in their farm activities. Moreover, the innovation helped clients to reduce not only their energy expenses but also the pressure on forest resources and the wider environment. Most of the rural people in Africa rely on forest resources as their source of energy, mainly for cooking, heating, and lighting purposes. This is causing a high rate of deforestation and environmental degradation. Biogas is providing alternative clean energy to the end users. Those farmers whose systems worked properly said they no longer bought or used charcoal or firewood or they consumed less compared to the amount they used before the innovation. Due to the cleanliness of the methane gas generated from their systems, users said they no longer suffer from indoor pollution, recalling when they cried while cooking with firewood. Clients also compared cooking with conventional gas to cooking with biogas. With biogas, users said even young children can do the cooking which would not be possible with the conventional gas due to its flammable nature.

*Methane gas being used for cooking and lighting*

Although lighting facilities were not in service in many of the biogas plants visited, two respondents did have working lighting systems and had replaced the use of kerosene.

## Waste management

One of the challenges rural dwellers in Africa have in common is the lack of proper sanitation facilities. They rarely have access to proper latrines, and animal dung adds to the problem. Humans do not live far enough from their livestock, causing chronic hygienic challenges.

In this field evaluation, however, it was found that the biogas innovation also provided rural users with sanitation benefits. Sanitation was the third most frequently mentioned (23%) benefit (Table 3). Farmers said before the innovation, they had piles of cow dung in their backyards or scattered all along their compounds, causing problems such as pest infestation and mosquitoes. A compound littered with cow dung also affected the appearance of their houses. Now that clients have biogas plants to use the cow dung, it is no longer considered as waste but rather as raw material or "gold." Moreover, to ensure sustainability and reliability of their systems, a couple of households had built toilets and connected them to their systems. Many more respondents wanted to or planned to do the same. By doing so, users keep their systems running and steadily generate outputs while also maintaining their indoor and outdoor hygiene. "Thanks to the biogas innovation, everything in our home is recycled. Cow dung and the waste from our latrine are directly fed into the system; we apply slurry from the system to seeds in our farm plot; we use the crop yields for our consumption and the crop residues for our animals. We no longer need rubbish bins to collect and dispose organic wastes," said a female respondent from Gulu district, Northern Uganda.

## Soil fertility and productivity benefits

The Green Heat innovator reports that the dry fertilizer separated by the SST is proven to boost crop yield by as high as 270 percent. Similarly, the respondents in the field were appreciating the high fertilizing effect of the bio-slurry byproduct. Enhancing soil fertility, and hence productivity, was the second most frequently stated benefit of biogas (98 percent) (Table 3). In the field, various farming practices were observed for the slurry, including crops grown on banana stems with slurry, vegetables grown in sacks full of slurry mixed with soil, and mushrooms grown in hanging plastic bags filled with slurry and soil. Farmers said the bio-slurry made the task of growing food easier and more flexible. The farmer pictured below said even people who live in rented houses can still grow crops on things such as a banana stem. He said, "Even if your landlord kicks you out, you can still move with your crops carrying your banana stem." For such good reasons, there is a very high demand for slurry, and not everyone has biogas plants.




*Food being produced in many ways using bio-slurry*

## Water benefits

Green Heat says its slurry separation system enables biodigesters to consume less water or reduces water needs of biogas plants by as much as 80 percent. In principle, water by-products are separated during the process of slurry separation and re-used to mix with organic waste later in the system – by replacing freshwater. This survey, however, shows a completely different outcome. Shortage of water was one of the major challenges identified by clients in relation to the innovation. Sixty-one percent of the interviewed households said their water consumption increased since they started to use biogas, mainly due to cow dung mixing. Only 21 percent said their water consumption was reduced due to biogas. But even that was because of some indirect effects of the byproduct. Respondents believed the reasons for improvement was due to the application of semi-liquid bio-slurry to crops, the slurry fertilizer shortening the growing season, and the fertile soil preserving the water.

When asked what they use the slurry for, most farmers said they directly apply it to their farm fields. Some said they sometimes reuse it to feed their system instead of cow dung but not as water. When

further asked why they wouldn't use recycled water to mix dung instead of freshwater, they said the residual or slurry is too thick to be used for mixing which was also confirmed during field visits. Farmers said they can only use the slurry to re-feed their systems, especially when there is a shortage of cow dung.

Based on observations, one main reason is that the separation process or SST was not effectively being executed. When inspecting the systems, it was noted that only a few had the facility to undergo the separation. For effective separation and recycling water, the outlet of systems need to be partitioned into two containers – one for the solid fertilizer and another for the liquid component (Photo 8, right). Unfortunately, most of the biogas plants visited had only one outlet where both components accumulate in the same container or directly flow to farm plots (Photo 8, left).

*Single outlet (left). Partitioned outlet (right).*

But Green Heat also reports that its biodigesters can be fed with a variety of liquids such as rainwater, wastewater, and cow urine. This was confirmed during the field visits. Customers were observed harvesting rainwater and collecting cow urine, including from their neighbors, to use for mixing. A male farmer from Buikwe district in the Central region of Uganda expressed the benefits of biogas innovation and said, "Thanks to the biogas technology, nothing of this cow is thrown away anymore. Her dung is used to feed our system to generate energy and her urine is used to mix the dung. Her milk is used to feed our children and the remaining is sold out to generate income. The more you feed her, the more she gives you dung and urine hence energy and fertilizer, and milk."

*Cow urine being used for mixing dung*

## Benefits of innovation on community

Respondents reported a wide range of knowledge and skill-sharing about biogas among their communities, and some consider themselves as "biogas promoters." Many users said they frequently receive visitors to see their systems. Some respondents adopted the innovation due to the experience of their friends or neighbors. Only two respondents mentioned that some community members made up stories of biogas plants causing pest infestation, such as mosquitoes. On the contrary, however, farmers used the fluid from bio-slurry as an organic pesticide by mixing it with unidentified locally available ingredients.

## Impact on poverty

Sixty-one percent (35 of 57) of respondents relied on agriculture as their primary source of income. However, farming is costly and requires a number of inputs, such as fertilizer, pesticides, herbicides, water, labor, and seeds. These could be reduced by using improved agricultural technologies, such as bio-slurry. Therefore, to determine the impact of the biodigesters equipped with slurry-separation innovation on users' livelihoods, a comparison of input consumption, expenses spent on inputs, the amount harvested, and income earned before and after the use of the systems was calculated. As a result, it was observed that the increase in crop yields and household incomes, as well as the reduction in consumption of inputs and associated expenses, was remarkable.

Based on observation, the impact of the technology on poverty alleviation was very visible. As shown in Table 7, users spent 1,081 percent less on inorganic fertilizers (mainly urea and dap) after the innovation. Each farmer spent UGX 46,693 less on average in a season. After the introduction of biogas and later SST, users switched to organic bio-slurry. But at the same time, crop yield and income of their households were increased. The average annual income of the sample households was UGX 3,787,302 before and UGX 5,581,724 after the innovation, a 47 percent increase. Similarly, the impact of the innovation on pesticides and herbicides consumption was promising. Farmers used less or no chemicals to prevent pests or herbs after the innovation. Moreover, clients' average energy expenses dramatically reduced after the innovation (346 percent less). Users said access to clean energy also improved their health and safety conditions. Fifty-four percent of farmers reported their income improved very significantly as a result of the innovation. Most of them sent their children to school with the new income.

# CONCLUSION

Green Heat was sponsored by SWFF to reach more farmers with their innovative Slurry-Separation Technology (SST) to biogas systems in Uganda and beyond. The intention of the SST was to enable biogas plants to separate water from the waste to be reused for mixing. Apart from recycling water, the technology was expected to create an easily managed, high-quality fertilizer product while increasing gas production for energy consumption. According to the innovator, the Green Heat SST would result in reduced water demand of biogas systems by as much as 80 percent, and the fertilizer would increase crop yield by as high as 270 percent. This field evaluation was, therefore, carried out to evaluate the performance of the biogas technology in general and the slurry-separation innovation in particular. The field survey was conducted in July and August, 2019, in Uganda. Although the biogas technology had been there for a long time, it was over four years since the slurry-separation innovation had been introduced.

The sample respondents interviewed included both men (51 percent) and women (49 percent) from 13 districts scattered across all the four regions of the Republic of Uganda. The average family size of samples was nine members, whereas, the average farm land holding was 5.9 hectares. Farmers' experience with biogas technology ranged from two months to 11 years.

Through the face-to-face interviews and personal observation, it was realized the innovation benefits users in many ways. Every respondent (100 percent) picked energy generation for cooking and lighting as the main benefit of the innovation. Enhancing soil fertility, and hence productivity, was the second most frequently mentioned benefit (98 percent). Fifty-four percent reported very significant improvement in their household income due to the innovation. Twenty-nine respondents said their average income increased by 32 percent annually after the innovation. The maximum yearly income registered before was UGX 16 million, and after the use of the Green Heat innovation, it elevated to UGX 25 million – up by 56 percent. Ninety-six percent confirmed improvements in crop survival rate. However, the innovation's impact on water consumption was not as promising as expected. Sixty-one percent of the interviewed households confirmed their water consumption increased after they started using biogas, which was attributed to the amount of water needed to mix dung. Only 21 percent reported their water consumption was reduced after biogas, but that was due to some indirect impacts not related to recycling. Moreover, the shortage of water was one of the major challenges identified by users. During the field visits, it was noticed that the SST was not being used by many of the farmers as intended to recycle water.

Overall, the project achieved countless remarkable successes toward improving farmers' livelihoods. The biogas systems offered users with clean energy, hygienic services, and environmental sustainability. In addition, the SST provided high-quality organic fertilizer that increased crop productivity and household incomes. However, some improvement is needed to properly administer and utilize the SST for recycling water. Through their wide range of purposes, biodigesters properly equipped with SST could contribute toward achieving most of the UN Sustainable Development Goals (SDGs). Among them are SDG 1: "Ending poverty in all its forms everywhere;" SDG 2: "Ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture;" SDG 6: "Ensuring availability and sustainable management of water and sanitation for all;" SDG 7: "Ensuring access to affordable, reliable, sustainable and modern energy for all;" and, SDG 13: "Taking urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy."

No communal or individual negative impact caused by biogas, or the SST in particular, was observed during the field survey.

# ANNEX I

## FARMER INFORMATION

NAME _____

AGE _____

DATE _____ TIME _____

GROUP INTERVIEW? ❑ Yes ❑ No

GROUP INTERVIEW NOTES

_____

_____

_____

HOW MANY FAMILY MEMBERS LIVE WITH YOU? _____

GENDER ❑ Male ❑ Female

WHAT IS YOUR PRIMARY OCCUPATION?

- ❑ Farming
- ❑ Wage Labor
- ❑ Seasonal Migrant Labor
- ❑ Small Enterprise
- ❑ Other: _____

DO YOU HAVE ANOTHER OCCUPATION?

- ❑ Farming
- ❑ Wage Labor
- ❑ Seasonal Migrant Labor
- ❑ Small Enterprise
- ❑ Other: _____

WHAT IS THE NAME OF YOUR VILLAGE/TOWN? _____

HOW MUCH LAND DO YOU OWN? _____

HOW LARGE IS YOUR FARM/PLOT?

- ❑ Large
- ❑ Medium
- ❑ Small
- ❑ Very Small

HOW MUCH IS LAND RENT? _____

OTHER LAND NOTES

_____

_____

_____

HOW LONG HAVE YOU BEEN USING GREEN HEAT? _____

DID YOU PARTICIPATE IN AGRICULTURAL ACTIVITIES THIS YEAR? ❑ Yes ❑ No

HOW MANY MONTHS IS THE PRIMARY GROWING SEASON? _____

HOW MANY TIMES DO YOU HARVEST PER YEAR? _____

## FARM INFORMATION

WHAT CROPS DO YOU GROW AS A RESULT OF GREEN HEAT? LIST FROM MOST IMPORTANT TO LEAST IMPORTANT:

1. _____

2. _____

3. _____

DID THE MOST IMPORTANT CROP BENEFIT FROM GREEN HEAT? ❑ Yes ❑ No

DID THE SECOND MOST IMPORTANT CROP BENEFIT FROM GREEN HEAT? ❑ Yes ❑ No

DID THE THIRD MOST IMPORTANT CROP BENEFIT FROM GREEN HEAT? ❑ Yes ❑ No

WHAT IS THE WATER SOURCE FOR YOUR IRRIGATION OF CROPS?

- ❑ Own pond
- ❑ River
- ❑ Groundwater
- ❑ Innovation Source
- ❑ Other _____

WHAT IS YOUR METHOD OF IRRIGATION?

- ❑ Drip feed
- ❑ Flooding
- ❑ Hand watering
- ❑ Rainfed
- ❑ Other _____

HOW MUCH HAS YOUR WATER USAGE CHANGED SINCE USING GREEN HEAT, IF AT ALL? _____

_____

USING GREEN HEAT HAS YOUR ACCESS TO WATER:

- ❑ Had no change
- ❑ Improved
- ❑ Fundamentally improved (Improved a lot)
- ❑ Other: _____

PREVIOUSLY GROWN CROPS: DID YOUR FARM PRODUCE DIFFERENT CROPS IN THE PAST THAT ARE NO LONGER GROWN HERE? IF SO, WHICH ONES? _____

_____

MASS OF PRODUCE: WHAT YIELDS DID YOU HAVE FOR EACH CROP YOU MENTIONED?? _____

_____

MASS OF PRODUCE 2: WHAT YIELDS DID YOU HAVE FOR YOUR CROPS BEFORE USING GREEN HEAT? _____

_____

USING GREEN HEAT HAVE YOU, FOR EACH CROP:

- ❑ Used more water
- ❑ Had no change in water use
- ❑ Used less water
- ❑ Other: _____

USING GREEN HEAT HAVE YOUR CROP YIELDS (ASK FOR EACH CROP):

- ❑ Declined
- ❑ Remained the same
- ❑ Increased
- ❑ Substantially increased

IS THERE A DIFFERENCE IN THE SURVIVAL RATES OF YOUR CROPS DUE TO GREEN HEAT?

❑ Yes ❑ No

HOW MUCH OF YOUR PRODUCE DID YOU CONSUME IN YOUR HOUSEHOLD? (PERCENTAGE – NOTE IF DIFFERENT FOR EACH CROP) _____

_____

HOW MUCH OF EACH OF THE FOLLOWING INPUTS DID YOU USE BEFORE GREEN HEAT?

FERTILIZER _____ (KG)
PESTICIDE _____ (KG)
HERBICIDE _____ (L)
CHARCOAL _____ (KG)
WATER _____ (TOTAL)
LABOR _____ (DAYS)
OTHER _____

HOW MUCH DID YOU SPEND ON EACH OF THE FOLLOWING INPUTS BEFORE GREEN HEAT?

FERTILIZER _____ (KG)
PESTICIDE _____ (KG)
HERBICIDE _____ (L)
CHARCOAL _____ (KG)
WATER _____ (TOTAL)
LABOR _____ (DAYS)
OTHER _____

HOW MUCH OF EACH OF THE FOLLOWING INPUTS DO YOU USE AFTER GREEN HEAT?

FERTILIZER _____ (KG)
PESTICIDE _____ (KG)
HERBICIDE _____ (L)
CHARCOAL _____ (KG)
WATER _____ (TOTAL)
LABOR _____ (DAYS)
OTHER _____

HOW MUCH DID YOU SPEND ON THE FOLLOWING INPUTS AFTER GREEN HEAT?

FERTILIZER _____ (KG)
PESTICIDE _____ (KG)
HERBICIDE _____ (L)
CHARCOAL _____ (KG)
WATER _____ (TOTAL)
LABOR _____ (DAYS)
OTHER _____

HOW MUCH DID YOU SPEND ON EQUIPMENT BEFORE AND AFTER GREEN HEAT GREEN HEAT?

HOW MUCH DID YOU SPEND ON TRANSPORT AND STORAGE BEFORE AND AFTER GREEN HEAT?

DO YOU HAVE PROBLEMS FINDING A MARKET TO SELL YOUR CROPS IN? ❑ Yes ❑ No
PLEASE EXPLAIN.

DO YOU HAVE PROBLEMS GETTING YOUR CROPS TO THE MARKET? ❑ Yes ❑ No
PLEASE EXPLAIN.

OTHER FARM NOTES (OPTIONAL).

## INCOME AND EXPENDITURES

WHAT IS YOUR ANNUAL HOUSEHOLD INCOME?

HOW MUCH INCOME DID YOU MAKE BEFORE GREEN HEAT?
AFTER GREEN HEAT?

HAS GREEN HEAT IMPROVED YOUR FAMILY INCOME?

WHAT PERCENTAGE OF YOUR INCOME DO YOU GET FROM NON-FARM SOURCES?

HOW MUCH PRODUCE DID YOU SELL FOR EACH OF YOUR CROPS IN THE LAST SEASON AND THE LAST YEAR?

WHAT IS THE PRICE PER KILO YOU RECEIVED FOR EACH OF YOUR CROPS FOR THE LAST SEASON?

_____

_____

USING GREEN HEAT HAS YOUR ACCESS TO CREDIT:

- ❏ Not improved
- ❏ Improved
- ❏ Improved and have been able to repay over a short period

HOW DO YOU CURRENTLY FINANCE AGRICULTURAL ACTIVITIES?

- ❏ Own savings
- ❏ Credit and savings scheme
- ❏ Other credit

HOW MUCH DO YOU PAY FOR GREEN HEAT? _____

HOW MUCH ARE YOU WILLING TO PAY FOR GREEN HEAT?

- ❏ Nothing
- ❏ GREEN HEAT is free
- ❏ The same as what I pay now
- ❏ 50% less
- ❏ 50% more
- ❏ Other: _____

HOW HAVE YOU SPENT YOUR NEW INCOME?

- ❏ N/A (if no new income)
- ❏ Send children to school or keep children in school
- ❏ Social functions (like weddings)
- ❏ Investment in farming
- ❏ Improving house
- ❏ Other: _____

OTHER INCOME NOTES (OPTIONAL)

_____

_____

_____

## PERCEPTIONS OF GREEN HEAT

WILL YOU USE GREEN HEAT IN THE FUTURE (5 TO 10 YEARS)? ❑ Yes ❑ No
PLEASE ELABORATE: _____

_____

HOW, IF AT ALL, HAVE YOU CHANGED YOUR FARMING PRACTICES DUE TO GREEN HEAT?

- ❑ No change
- ❑ Introduced new crops
- ❑ Changed irrigation system
- ❑ Reduced water usage
- ❑ It helps me decide when to plant
- ❑ It helps me decide which crops to plant
- ❑ Other: _____

HAVE YOU FACED ANY DIFFICULTIES OR PROBLEMS USING GREEN HEAT? ❑ Yes ❑ No

HOW CAN GREEN HEAT BE IMPROVED? _____

_____

HOW DID YOU HEAR ABOUT GREEN HEAT?

- ❑ Wealthy farmer
- ❑ Neighbor
- ❑ Innovation personnel
- ❑ Extension worker
- ❑ Other: _____

WHAT FACTORS INFLUENCED YOU TO TRY GREEN HEAT?

- ❑ Demonstration from neighbor's farm
- ❑ Innovation is free from extension services
- ❑ No alternative water source
- ❑ Other: _____

DO YOU SHARE YOUR KNOWLEDGE SKILLS FROM GREEN HEAT WITH OTHERS? ❑ Yes ❑ No
IF SO, HOW? _____

_____

_____

WHAT DO YOU FEEL ARE THE BENEFITS OF GREEN HEAT? _____

_____

_____

HAVE YOU HEARD ABOUT CLIMATIC VARIATION? HAVE CHANGES IN RAINFALL OR TEMPERATURE AFFECTED YOUR FARMING PRACTICES OR CROP YIELDS COMPARED TO YOUR HISTORICAL RAINY/DRY SEASON PERIODS? ❑ Yes ❑ No

PLEASE SPECIFY HOW. _____

_____

HOW HAS GREEN HEAT HELPED YOU? PLEASE RANK THE TOP 3 AND EXPLAIN POSITIVES/ NEGATIVES.

☐ Makes water reusable _____

☐ Helps women farmers as well as men _____

☐ They made a special effort to include women farmers _____

☐ Helps in producing more of our most important crop _____

☐ Increases my yield through timely forecasts _____

☐ Helps by lowering cost of inputs _____

☐ Improves health and strength of livestock _____

☐ Helps reduce labor _____

☐ Reduces crop wastage _____

☐ Helps me decide when to plant _____

☐ Helps me decide which crops to plant _____

☐ Other: _____

WOULD YOU RECOMMEND GREEN HEAT?

❑ No
❑ Yes
❑ Yes, would strongly recommend

ARE THERE NEGATIVE IMPACTS FROM GREEN HEAT IN THE COMMUNITY? ❑ Yes ❑ No

IF YES, PLEASE EXPLAIN. _____

_____

_____

IF THERE HAVE BEEN ANY NEGATIVE IMPACTS, HAVE EFFORTS BEEN MADE TO RESOLVE THEM?
❑ Yes ❑ No

EXPLAIN. _____

_____

_____

DO YOU HAVE PROBLEMS FINDING A MARKET TO SELL YOUR CROPS IN? ❑ Yes ❑ No
EXPLAIN. _____

_____

_____

DO YOU HAVE PROBLEMS GETTING YOUR CROPS TO THE MARKET? ❑ Yes ❑ No
EXPLAIN. _____

_____

_____

HAVE CHANGES IN RAINFALL OR TEMPERATURE AFFECTED YOUR FARMING PRACTICES OR CROP YIELDS COMPARED TO HISTORICAL RAIN/DRY SEASON PERIODS? ❑ Yes ❑ No

## OTHER

INCOME/POVERTY NOTES

_____

_____

GENDER OBSERVATIONS

QUESTIONS/REQUESTS

OTHER NOTES

SECURING
WATER
FOR FOOD:
A GRAND CHALLENGE
FOR DEVELOPMENT

Securing Water for Food has sourced and invested in a portfolio of innovative solutions that aim to help farmers use water more efficiently and effectively, improve water storage for lean times, and remove salt from water to make more food. Our cohort of innovators are helping people in 35 low-resource countries with tools they need to produce more food with less water.

To learn more about Securing Water for Food,
visit www.securingwaterforfood.org.