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Biogas in Uganda and the Sustainable Development Goals: A Comparative Cross-Sectional Fuel Analysis of Biogas and Firewood

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Abstract: Biogas technology has the potential to achieve at least eight of the Sustainable Development Goals (SDGs). This study assessed household biogas consumption against firewood and its socioeconomic and environmental impacts with regard to achieving the SDGs in the Iganga District, Uganda. In addition, factors hindering the adoption of biogas technology were assessed. Data were collected from 314 respondents using a questionnaire, interview, and observation. A mixed analytical approach combined descriptive analysis, multivariate analysis of variance and one-way analysis of variance tests to compare the impacts of biogas and firewood use and identify factors hindering the adoption of biogas technology. Results show that biogas consumption contributed to higher socioeconomic, health and environmental benefits than firewood. Biogas positively impacted SDG7, and indirectly, SDGs 2, 3, 5, 6, 8, 9, and 13. An estimated 46.9% of households perceive biogas as a clean fuel. The factors motivating biogas consumption include its smoke-free nature, women and children having more time to engage in other development activities and reduced time spent on cooking. In conclusion, biogas offers higher impacts on SDGs compared to firewood. Reviewing the current national renewable energy promotion frameworks to provide biogas subsidies to households and investors can contribute to increasing biogas consumption in households.

Keywords: biogas; energy consumption; biogas energy; biogas technology; sustainable development; Uganda

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Citation: Mukisa, P.J.; Ketuama, C.T.; Roubík, H. Biogas in Uganda and the Sustainable Development Goals: A Comparative Cross-Sectional Fuel Analysis of Biogas and Firewood. *Agriculture* **2022**, *12*, 1482. https://doi.org/10.3390/agriculture12091482

Academic Editor: Dongyang Liu

Received: 20 July 2022
Accepted: 13 September 2022
Published: 16 September 2022

1. Introduction

On the African continent, access to electricity and modern energy used for cooking remains a major concern for domestic and commercial activities. Most of the population around the world, including over 2.7 billion people in sub-Saharan Africa, rely predominantly on traditional biomass for cooking [1]. Energy obtained from biofuels and waste contributed 10.4% of global energy consumed in 2019 [2]. The potential for biogas generation is high on the African continent, although the use of available resources for sector development is low. Technical problems, insufficient laws and finances are some of the barriers to biogas production and use [3–5].

In Africa and Asia, most installed biogas systems are small-scale and used at the household level, except for in India and China, where large-scale biogas systems are increasing and are basically used for heating and electricity [6]. Where large amounts of waste are generated, the installation of large-scale biogas systems is a viable option. This is possible in biogas production companies, educational institutions, wastewater and excreta management organisations and hospitals, among others [7,8].

Biomass is the main energy source for cooking in rural areas of East Africa, including Uganda. For those who consume biogas as alternative energy, access to organic feedstock, such as animal waste, is made available for continuous production [9,10]. Uganda's installation of biogas technology was introduced by the Church Missionary Society (CMS) in the 1950s [11]. Under the African Energy Program, between the 1980s and 1985, the

Commonwealth Council built biogas demonstration plants and disseminated fuel-efficient stoves [12]. To encourage the rural and semiurban population to adopt the technology and benefit from using clean energy for cooking, lighting and as bioslurry to improve yields, the Ugandan government created the Uganda Domestic Biogas Program (UDBP) in 2008. Various biogas plants were installed in the Eastern, Western and Central regions of Uganda and were promoted by the Ministry of Energy and Mineral Development (MEMD) and the National Agricultural Research Organization (NARO), with the collaboration of other projects and NGOs such as the Heifer Project International (HPI) and SNV [13,14]. Through the Dutch government's African Biogas Partnership Program (ABPP), biodigesters were constructed between 2009 and 2013 in Uganda, Kenya, Burkina Faso and Tanzania to increase adoption rates. However, by 2016, 25% of them had been abandoned [3,5].

Uganda has seen a steady increase in waste streams, such as from abattoir, municipal and animal waste, that can be used for biogas generation. In recent years, 1400 tons per day of municipal waste are collected and landfilled, with an annual waste generation of 481,081 tons in the country by 2017, according to the Kampala Capital City Authority [15]. Despite the presence of such resources, approximately 90,000 hectares of forest cover are lost annually. There has been an increase in deforestation due to the high demand for firewood, used mainly for cooking by the rural population; charcoal is used by most of the urban population; and timber is used for building construction [16]. Insufficient funding, weak institutions, limited capacity and the uncoordinated implementation of policies between stakeholders in the economy are the different barriers attributed to the low effectiveness and efficiency in developing and managing forest resources sustainably in Uganda.

The transition to renewable energy sources including biogas is considered as a pathway to a sustainable energy supply around the world. The biogas market size in Europe increased from USD 1.67 billion in 2020 to 1.87 billion in 2021 [17], whereas Uganda's biogas initiatives are failing [5] and contributing to the forest loss of 967 kha from 2001 to 2021, in addition to several drivers including firewood collection [18]. Despite the feasibility of bottling biogas in Uganda [19], the consumers' behaviour (acceptability, intentions and willingness to pay) is not yet known. In a previous study in Uganda, farmers were willing to pay ten times less than the normal cost for plastic biogas digesters [20]. This, in part, explains why firewood is still in high demand in households due to its low cost or free collection. This behaviour is hindering local economic growth, poverty reduction and environmental protection. In this light, this study seeks to correlate the narrative of impacts of biogas on the SDGs with empirical evidence to explore sustainable pathways of biogas development in Uganda. Such pathways could, on the one hand, increase the funding of household and community biogas interventions in a systemic manner; not only to reduce firewood consumption, but with a special focus to attain the SDGs. On the other hand, integrating the entrepreneurial business model [14] is a useful pathway. Although empirical evidence on the role of biogas in attaining the SDGs is not known, this study seeks, firstly, to understand whether the use of small-scale biogas technologies such as firewood offer significantly higher socioeconomic and environmental benefits to the users in the Iganga District. Secondly, these impacts are linked to the SDGs based on a mapping of indicators identified by [21]. Finally, the factors hindering the adoption of biogas technology in the Iganga District were assessed.

2. Materials and Methods

The study was carried out in three sub-counties of the Iganga District (Iganga Municipal Council, Namungalwe and Nakalama, Iganga-Uganda), as shown in Figure 1. Iganga is a district in the eastern region of Uganda with a total population of approximately 505,405 inhabitants and a land size of 1046.75 km^2. The district has more than 102,472 households, of which only 17,521 (17.1%) have access to electricity. About 90.4% of households practice crop production, 65.7% are involved in livestock production and 92.5% practice both crop and livestock production. Households (45.2%) dispose solid waste using skip bins provided by the municipal authority. The number of households in the selected sub-counties was Nakalama—9167, Namungalwe—7638, and Iganga Municipal Council—14,065, totalling 30,870 households [22].

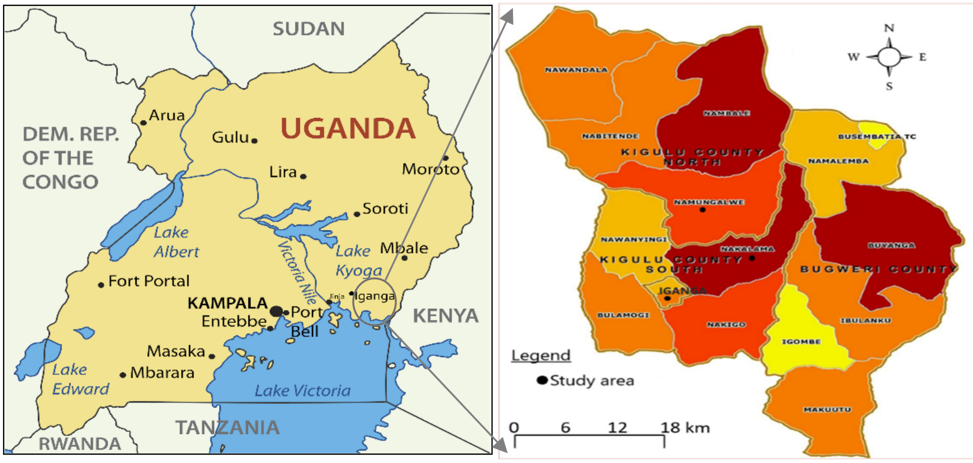

Figure 1. Map of the study areas.

2.1. Description of Target Population and Data Collection

A stratified sampling approach enabled the selection of households (n = 300); local government officials (n = 6); and NGOs (n = 8) for the study. Households are known to generate volumes of waste that can be used in biogas generation. Additionally, they are directly affected by the use of biogas and firewood. NGOs are knowledgeable, have the expertise, advocate for policy change and create awareness among the public. They also act as intermediaries between the government and the public. For local government officials, they play a very vital role when it comes to the development and implementation of policies.

Data were collected from May to July 2021 using a questionnaire survey. The questionnaire was divided into five sub-sections, including basic information about household heads, biogas plant information, the impact of biogas and firewood, and factors affecting biogas adoption (perception and motivation). Semistructured interviews were administered to local government officials and NGOs to collect data on waste management practices, biogas use and related issues. Each interview took about 30 min per participant.

2.2. Data Analysis

Data were classified, categorised and coded, and a statistical analysis was performed using Microsoft Office Excel and the Statistical Package for the Social Sciences (SPSS) version 20. A descriptive statistical analysis was performed on selected aspects of biogas production (type of digester, feedstock used, appliances, purpose of use, alternatives to biogas), perceptions and motivations for adopting biogas. The multivariate analysis of variance test (MANOVA) was used to determine and compare the benefits of biogas and firewood on households by testing for any significant differences between the benefits of biogas technologies and firewood. This was followed by the mapping of the benefits (impacts) of biogas technology to the indicators of the SDGs based on the impact indicators of biogas energy consumption identified by [21]. Finally, a one-way analysis of variance (ANOVA) test was used to identify the factors hindering the adoption of biogas technologies in households in the Iganga District.

3. Results

3.1. Presence of Biogas in the Household

The majority (60.3%) of households (n = 158) had biogas installed in their households, whereas 37.7% did not have biogas plants installed (n = 104) (Table 1). The fixed dome digester (91.1%) is the most widely used biogas plant, followed by the balloon (5.7%) and the floating drum (3.2%) (Table 1). Among households, animal waste (84.6%) is the most used feedstock for biogas generation, and human waste represents 15.4% (Table 1).

Table 1. Aspects of household biogas production and use.

Aspect	Description	Frequency (*n*)	Percentage (%)
Biogas presence in the household	Have biogas installed	158	60.30
	Have no biogas installed	104	39.70
Type of digester	Fixed dome	144	91.10
	Balloon	9	5.70
	Floating drum	5	3.20
Feedstock used	Animal waste	143	84.60
	Human waste	26	15.40
Purpose of the energy	Cooking	152	59.40
	Lighting	95	37.10
	Heating	8	3.10
	Other reasons	1	0.40
Appliances used	Biogas stoves	142	53.40
	Biogas lamps	93	35.00
	Biogas cookers	9	24.00
	Refrigerators	7	2.60
Alternative energy source	Firewood	86	41.30
	Solar	42	20.20
	Hydropower	68	32.70
	Fuel generators	4	1.90
	Others	8	3.80

The biogas generated is used mainly for cooking, representing 59.4% of the households. The percentages of households that use it for lighting, heating and other reasons is 37.1%, 3.1% and 0.4% respectively (Table 1). However, when it comes to the appliances used, biogas stoves account for 53.4%, biogas lamps for 35%, whereas biogas cookers (9%) and refrigerators (2.6%) are the least used. For those without biogas digesters (41.3% of households), firewood is the most common energy source used for cooking, whereas hydroelectric power (32.7%) is the most used for lighting.

3.2. Perception and Motivation for Biogas Use

With respect to household heads' perceptions of the use of biogas and firewood, 46.9% and 34.5% of the respondents perceived biogas as a clean energy source, that is, it is smoke-free, and that once the technology is installed, it is easy to maintain and operate. Other responses accounted for 4.3% and 4%, indicating that biogas installation is less cost-effective and biogas is dangerous because it is generated from animal dung and human excreta (Figure 2).

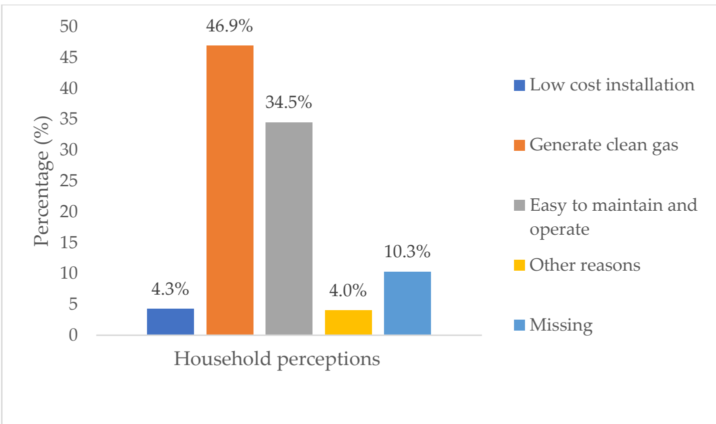

Figure 2. Household perceptions toward biogas use.

Furthermore, Table 2 presents the responses of the households on the motivating factors that lead them to use biogas. The mean scores for all motivating variables were significant. The results showed that biogas being smoke-free (5.84) is the most important variable as to why biogas is used. The variable "government subsidies" (1.35) was the least motivating factor for adopting household biogas. The responses collected were triangulated with the data collected from the interviews, where it was observed that the Ugandan government has played little or no role in supporting the community in the use of energy and in increasing the adoption, compared to NGOs that have tried to support the community, both financially and technically. This could be due to the development and implementation approaches used (top–bottom).

Table 2. Motivating factors toward biogas adoption.

Factor	Mean	Std. Deviation	Variance	Skewness	Kurtosis
It is smoke-free	5.84	0.384	0.148	−2.301	4.494
Women and children have time to participate in other developmental activities	4.46	0.791	0.625	−0.788	1.106
Time spent on cooking is reduced	4.35	0.879	0.773	−0.340	0.411
Easy to use	2.49	0.731	0.534	0.248	0.404
Saves money	2.46	0.824	0.679	0.206	−0.077
Subsidies given by the government	1.35	0.950	0.902	3.123	9.720
Valid N (listwise)	262				

The findings of the survey by [23] on SNV-supported domestic biogas programs in Asia and Africa, specifically those conducted in Uganda, Kenya and Tanzania, with a focus on understanding the decision-making process on biogas adoption, indicated that the use of biogas saves time and money, which encourages people to engage in other activities, in addition to generating clean energy. All the responses discussed depict the gender sensitivity aspect among the participants, and this can lead to an improvement in the wellbeing of women and children. This is because, in African culture, women and children are expected to do all domestic-related chores.

3.3. Impact of Biogas Consumption against Firewood on Households

Socioeconomic and environmental factors were analysed to understand whether there is a significant impact when small-scale biogas technologies versus firewood are used by households in the achievement of the SDGs. Using an alpha level of 0.05, the results of the MANOVA test analysis indicated that biogas technologies relative to the use of firewood had a significant effect on socioeconomic, health and environmental variables that contribute to achieving the SDGs. The results showed *p*-values (0.71, 0.56 and 0.88) greater than the set alpha level (Tables 3–5).

Table 3. Socioeconomic benefits of adopting biogas plant over use of firewood.

Effect	Multivariate Tests					
	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	0.02	0.673 [a]	8.00	253.00	0.71	0.02
Wilks' lambda	0.98	0.673 [a]	8.00	253.00	0.71	0.02
Hotelling's trace	0.02	0.673 [a]	8.00	253.00	0.71	0.02
Roy's largest root	0.02	0.673 [a]	8.00	253.00	0.71	0.02

Each F tests the multivariate effect of biogas installed. These tests are based on linearly independent pairwise comparisons among the estimated marginal means. [a] = significant at 5% level.

Table 4. Health benefits of adopting biogas technology.

Effect	Multivariate Tests					
	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	0.01	0.696 [b]	3.00	258.00	0.56	0.01
Wilks' lambda	0.99	0.696 [b]	3.00	258.00	0.56	0.01
Hotelling's trace	0.01	0.696 [b]	3.00	258.00	0.56	0.01
Roy's largest root	0.01	0.696 [b]	3.00	258.00	0.56	0.01

[b] = significant at 1% level.

Table 5. Environment benefits of adopting biogas technology.

Effect	Multivariate Tests					
	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	0.00	0.129 [a]	2.00	259.00	0.88	0.00
Wilks' lambda	1.00	0.129 [a]	2.00	259.00	0.88	0.00
Hotelling's trace	0.00	0.129 [a]	2.00	259.00	0.88	0.00
Roy's largest root	0.00	0.129 [a]	2.00	259.00	0.88	0.00

[a] = significant at 1% level.

Regarding the socioeconomic benefits of using biogas technology (Table 3), all variables had a significant impact, implying a significant role in achieving SDG2 (zero hunger), SDG5 (gender equality) and SDG8 (decent work and economic growth). The results indicated that the reduced cooking time (0.78) and the use of bioslurry to increase crop yields (0.77) were the highest benefits obtained from the use of biogas by households. This was followed by women and children having more time to engage in educational and productive activities (0.62), and subsequently, increasing household savings and incomes (0.52), reducing costs of waste removal (0.45), increasing energy supply and reduced time spent on firewood collection (0.39) and creating employment (0.29). The authors of [24,25], in their studies, argue that the workload for women and children in rural areas is reduced by 50%, and they often have adequate time to participate in other productive activities when biogas is used.

The evaluated health benefits (Table 4) showed a significant impact. In particular, the most recognised benefit was the increase in life expectancy of household members (0.98). This was followed by serving as a waste disposal and sewage method (0.70) and reducing eye and respiratory infections caused by smoke from wood (0.42). All these benefits were identified to promote the achievement of SDG3 (good health and wellbeing) and SDG7 (affordable and clean energy for all) in the short or long term. When household hygiene is improved, the health of people is also improved, implying an increase in savings and labour productivity. A similar study by [3] showed that cooking increased the life expectancy of household members through improved waste management and sanitation.

In an analysis of the environmental benefits of biogas use (Table 5), biogas use had the greatest effect on the reduction in deforestation (2.85). The biogas effect on the reduction of greenhouse gas emissions in the household had a mean score of 1.38. Reduced air pollution (1.77) was the smallest effect due to the use of biogas according to the responses of the participants. All results were significant, which means that they play a significant role in achieving SDG13 (climate action) related to climate change, although in the long term. In fact, ref. [26] argued that anaerobic digestion reduces greenhouse gas emissions, which is the main issue in recommending biogas production. A summary of the impact of biogas consumption on the SDGs is shown in Table 6.

Table 6. Impact of biogas consumption on SDGs.

SDG	Biogas Impact
Goal 2. Zero hunger	Increased crop yield. Valorisation of non-arable land.
Goal 3. Good health and wellbeing	Reduced cooking time. Reduced firewood collection burden. Higher life expectancy.
Goal 5. Gender equality	Builds user's technical capacity. Women empowerment, rendering them independent. Women and children have time to participate in other developmental activities.
Goal 6. Clean water and sanitation	Improved household sanitation. Reduced household particulate matter concentration.
Goal 7. Affordable and clean energy for all	Smoke-free. Affordable technology for cooking and electricity generation.
Goal 8. Decent work and economic growth	Job creation for the household members. Increased economic growth through the trading of biogas equipment.
Goal 9. Industry, innovation, and infrastructure	Low-cost technology. Easy to operate and maintain biogas plant.
Goal 13. Climate action	Reduction of greenhouse gas emissions.

3.4. Factors Hindering the Adoption of Household Biogas Technologies

A one-way ANOVA test was used to analyse the factors hindering households' adoption of biogas technology. An estimated 45% of the households responded that inadequate access to biogas knowledge and technical expertise prevented them from adopting the technology. A minimum percentage of 7.3% of respondents indicated that having a very high access to biogas knowledge and technical expertise increased biogas adoption. This indicated that access to knowledge regarding biogas and technical expertise are the main factors that prevent household adoption of biogas technology, as shown in Figure 3.

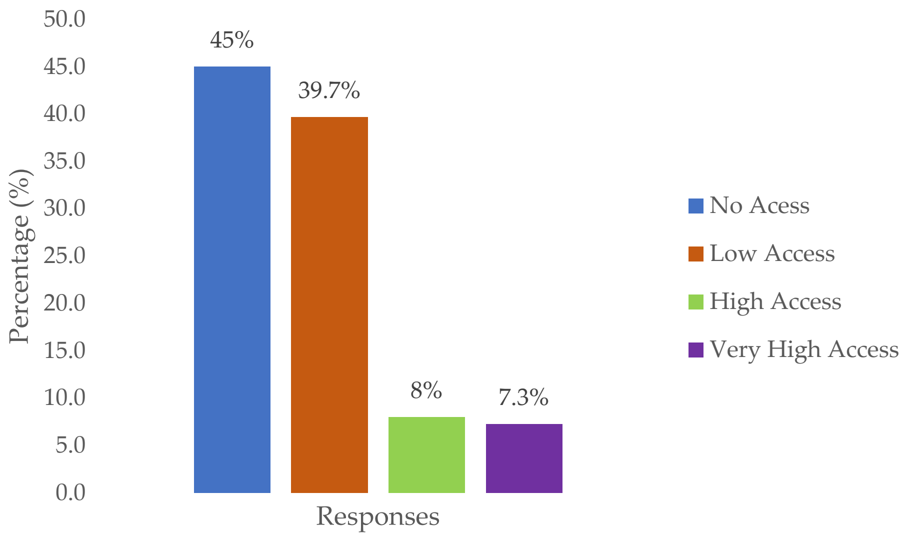

Figure 3. Access to biogas knowledge and technical expertise.

This implies that having adequate knowledge about an aspect being encouraged plays an important role in the decision-making process. It expands the perception of the individual about the issue and educates them more about its benefits once it is implemented. The study findings are in support of the findings of [27,28] on the factors that influence the adoption of biogas. Their results argued that having limited awareness about the technology, in addition to having limited access to the technocrats of the technology, acts as a barrier to accepting the technology. The one-way ANOVA test revealed that access to biogas knowledge and technical expertise did not contribute to the low adoption of biogas technology. The F-ratios for all other variables used in the analysis were higher than the set alpha level of 0.05. However, their *p*-values (0.00, 0.13, 0.21, 0.24, 0.44 and 0.03) were at $\alpha = 0.05$. Amongst the six variables, two variables, "no access to sufficient supply waste" and "biogas being more expensive than other sources of energy", had statistically significant differences between the mean scores with *p*-values (0.00 and 0.03) lower than the $\alpha = 0.05$. This meant that the hypothesised "access to biogas and technical expertise" as the main factor was rejected. This could be due to the availability and accessibility of feedstock from the agricultural activities in the households. Therefore, this does not affect the adoption rates for biogas in the area. On the other hand, four variables had non-statistically significant results: "no sufficient government support" (0.13), "firewood readily available feedstock" (0.21), "initial investment too high" (0.24) and biogas is dangerous (0.44) were greater than the set alpha level. These results showed evidence that the set hypothesis was true, and therefore, these factors were considered for hindering the adoption of biogas technology. Similarly, the findings of [29,30] on the factors that hinder the dissemination of biogas included a lack of knowledge and access to appropriate technical services, in addition to the high investment cost and insufficient government support. Therefore, to facilitate the diffusion of biogas technology, external assistance is needed through awareness creation and the extension of subsidies to households that cannot afford to pay all costs for the installation of biogas plants.

4. Conclusions

Biogas energy still retains a significant unexploited potential in Uganda. This study was aimed at comparing the benefits of biogas and firewood to reveal action gaps that are needed to reduce the consumption of firewood and improve biogas consumption in rural households of the Iganga District of Uganda. Results showed that biogas technology offers higher socioeconomic and environmental benefits compared to firewood consumption. Promoting biogas consumption in this district would contribute to majorly achieving Sustainable Development Goals 2, 3, 5, 6, 7, 8, 9, and 13. Most of the respondents are motivated to use biogas because it is clean and can reduce the burden of collecting and burning firewood. The development of biogas technology is still affected by several barriers, with the most significant being the lack of investment capital, and inadequate access to knowledge and technical expertise to sustain the technology. Other barriers include low government support, and easy and, at times, free access to firewood. This has, consequently, reduced biogas consumption in households. Firewood consumption is also contributing to deforestation and delaying the achievement of the SDGs in the district. The comparative analysis of biogas and firewood consumption has provided evidence to link biogas production to the SDGs, through which joint interventions could contribute to accelerating biogas use in Iganga District households.

Author Contributions: Conceptualisation, H.R.; methodology, P.J.M. and H.R.; formal analysis, P.J.M.; investigation, P.J.M.; resources, H.R.; data curation, P.J.M.; writing—original draft preparation, P.J.M. and H.R.; writing—review and editing, P.J.M., C.T.K. and H.R.; visualisation, P.J.M.; supervision, H.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, grant number IGA (20223111).

Data Availability Statement: Data can be requested from corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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