Norwegian University of Life Sciences

Master's Thesis 2020 30 ECTS
Environmental Sciences and Natural Resource Management

Is biogas a viable technology for domestic cooking purposes in rural Uganda?

Helene Maria Aamodt
Renewable Energy

Acknowledgment

Five years at the Norwegian University of Life Sciences have come to an end. These years have been an adventure I could never have foreseen in my wildest dreams. First of all, I want to thank the University, all of my professors, and all my fellow students at Sørhellinga. Thank you to Erik, my supervisor, for guidance and input. I want to thank all the safaris to the local waterhole, better known as "Bodegaen". I want to thank all the people who have made me dinner and kept me alive, as my mom uses to say, "without food and drinks, the hero doesn't work".

I had a dream that I would one day contribute to making the world a better place, even the slightest of positive change. I am therefore so grateful that I got the opportunity to work with Engineers Without Borders and Nyenga Foundation in Uganda to write this thesis. I want to give a special thanks to my mentor, Johannes, who took time off work to help me with my fieldwork and also was a great travel companion. Thank you to all participants and informants in Uganda. I am very thankful to the whole Nyenga Foundation for making us feel most welcome; it was an experience I will never forget. I will also never forget the sight of a giraffe drinking or the baboons chasing us. All the superheroes in Eplehagen should be mentioned as well for making quarantine into a dance party. Who would have known that life between fields in Ås would be so fantastic? A great appreciation is deserved to my family and friends; life is good with you around.

Finally, I want to thank the first friendly face I met in Ås and the magnificent buddy, Tonje, for a fantastic buddy-week (or half-year), well-executed training in the Ås-spirit and an excellent follow-up service throughout the student years.

Well done and skål!

Abstract

Sustainable development and renewable energy security are global concerns today. In developing countries, these challenges are coupled with increased energy demand. Firewood and charcoal are the most used cooking fuels in Uganda, as only a small percentage has access and economy to use electricity. Wood fuel has many adverse side effects for people, nations, and the environment, which promotes a need for sustainable alternatives. Biogas plants transform organic waste with low value into gas and fertilizer for plants. A biogas plant could benefit many parties, but several critical factors can inhibit the viability of the system.

This thesis aims to explore if biogas is a viable technology for domestic cooking purposes in rural Uganda by asking; What are the costs and benefits of domestic biogas plants for the user in rural Uganda?, II: What are the criteria for a successful implementation of domestic biogas plants? and III: What are the critical factors for a successful implementation for domestic use? The research questions were answered by the use of two methods; 1) Literature review of studies of technology implementation and domestic biogas plants in developing countries and 2) Qualitative interviews with participants and fieldwork in rural Uganda. The results of the economic assessment on the Nyenga Foundation's biogas plant showed that biogas is the cheapest cooking alternative compared to wood fuel, LPG, and electricity. However, the investment cost of a domestic biogas plant is high, which can be a significant challenge for many stakeholders.

A successful biogas plant has a lasting and expanding operation, and a user owning the knowledge and handling challenges. Various factors are critical to the implementation of domestic biogas plants; economic, technical, environmental, cultural, social, and institutional, which must be addressed to see successful implementation. The participants showed that the most critical barriers to a domestic biogas plant were owning the knowledge of the plant and using it to plan an effective biogas system from cow to field. The results implicate a necessity of spreading knowledge and the benefits of biogas plants. The information shared should include suggestions on making a sustainable system where all the biogas plants' benefits are utilized.

Table of contents

Tables

Figures

Equations

1 Introduction

1.1 Sustainable development

Sustainable development and renewable energy security are concerns to the world as the climate changes are happening. In the developing world, the majority of people do not have access to electricity today, and Uganda is no exception. According to the Uganda Vision 2040, only 12 % of the population uses electricity from the national grid, and 95 % use wood fuel as their primary energy resource (The National Planning Authority, 2013). Firewood and charcoal have become more expensive fuels due to deforestation and increasing demand. The situation has created an opportunity for other cooking technologies to emerge.

Domestic biogas plants have become more popular as they have many advantages compared with traditional stoves; higher efficiency, timesaving, and without the harmful smoke. The substitution of wood for biogas relieves the pressure on the forests and biodiversity while decreasing greenhouse gas emissions (Clemens et al., 2018). Biogas plants could benefit both individual households, larger organizations and society, and national development. According to the United Nations' Third synthesis report on technology needs (United Nations, 2013), the most attractive technologies for minimizing greenhouse gas emissions among developing countries worldwide is biogas technology. Roopnarain and Adeleke (2017) state that biogas technology has a substantial and unexploited potential in several developing countries, including the East African countries. Although the potential is high for biogas production, some barriers and challenges are hindering a broad implementation of the technology. Several projects have tried to create a wave of installed biogas plants in developing countries. Despite the biogas' many advantages, numerous plants are abandoned after a few years (Wassie and Adaramola, 2019).

This thesis explores if biogas is a viable alternative for cooking purposes in rural Uganda and to whom. Criteria for success, critical factors, and technology implementation are emphasized. Earlier studies have mainly analyzed the potential benefits and challenges of having domestic biogas plants in developing countries. In contrast, this thesis aims to include the critical factors for successful implementation and the criteria for claiming success.

Biogas plants use organic waste, typically animal manure or food waste, to anaerobically produce methane (CH4) and carbon dioxide (CO2). A biogas plant works like a ruminant's digestive system; it is fed with nutrients to produce biogas and the residue, called slurry (Roopnarain and Adeleke, 2017). The gas can be directly used for cooking purposes by a gas stove, or it can be used to generate electricity or upgraded to vehicle fuel (Tabatabaei and Ghanavati, 2018). The slurry has more available nutrients as methane and carbon dioxide produced, which makes it an excellent fertilizer for plants (Roopnarain and Adeleke, 2017). The biogas yield is dependent on the temperature in the digester as the microbial bacteria in the substrate mix are producing methane at certain temperatures, preferably between 25˚C and 55˚C (Hagos et al., 2017). The warmer climate in countries near the equator is therefore ideal for a straightforward biogas plant. In contrast, the countries with a colder climate need additional heating to achieve a good methane yield (Tabatabaei and Ghanavati, 2018). Most organic materials can produce biogas, although the most common in East Africa is dung from cows or pigs (Roopnarain and Adeleke, 2017, Clemens et al., 2018). The inclusion of several types of substrates, like animal dung and food waste, in a co-digestion increase the potential methane production considerably (Hagos et al., 2017).

Compared with other developing countries, and especially in Asia, there is evidence of slow biogas implementation in the African continent (Patinvoh and Taherzadeh, 2019, Roopnarain and Adeleke, 2017). The African Biogas Partnership Program (ABPP), a program under the wings of Hivos and SNV, reports of 7 628 installed biogas plants in Uganda (ABPP, 2020). Although the number of biogas plants in Uganda is increasing, a higher implementation rate is seen in Kenya and Ethiopia, with more than 18 500 plants installed in each country (ABPP, 2020). Biogas plants have started to become more common in rural Uganda during the last decade

Uganda is a country in development, and the National Planning Authority of Uganda created a national Vision for Uganda's development towards 2040. The Uganda Vision 2040 states that the government of Uganda will promote biogas development to expand access to energy in rural areas towards 2040 (2013). However, the government had already set a highly ambitious goal of installing 100 000 biogas plants within 2017 (Roopnarain and Adeleke, 2017), which is far from achieved, although many plants are installed. The high upfront installation costs could explain the low adoption rate, the lack of technically skilled people, and the stigma of using waste for energy and fertilizer (Roopnarain and Adeleke, 2017). Uganda's ambitious development goals are evident in its vision for 2040. The Ugandan government aims for 80 % national electricity coverage in 2040, whereas the status of 2010 is 11%. In 2010 the electricity consumption per capita was 75 kWh, and the vision aims to increase to 3 668 kWh within 2040. The ambition equals a growth of ca. 4 800 % in 50 years. Furthermore, the Ugandan government aims to increase innovation, measured in patents, with 2 000 % within 2040. This goal is not technology or sector specified, which could be seen as unimportant due to only having three new patents a year in 2010.

The African Biogas Partnership Program (ABPP) was established in 2009 to promote and widespread biogas technology in several Sub Saharan countries to increase the development of nations and individuals (Clemens et al., 2018). In 2018, Clemens et al. published a review of the ABPP's two phases with their strategies and the results so far with a particular focus on Kenya, Tanzania, and Uganda. The ABPP promoted a marked for biogas plants and an implementation strategy, which the countries are expected to implement in their policies (Clemens et al., 2018). The widespread of biogas technology is still low in Africa compared to other developing countries in the world. However, a significant improvement has been visible after technology promoting and enabling programs as ABPP (Roopnarain and Adeleke, 2017).

1.2 Objectives

The overall objective of this thesis is to analyze whether domestic biogas plants are a viable solution for cooking purposes in rural Uganda. The following questions are asked to answer this:

I. What are the costs and benefits of domestic biogas plants to the user in rural Uganda?
II. What are the criteria for a successful implementation of domestic biogas plants?
III. What are the critical factors for a successful implementation for domestic use?

The implementation of biogas technology in rural Uganda is discussed with an emphasis on the benefits and challenges of the household or biogas owner. An economic evaluation of a plant installation was completed, and the critical factors of implementing new technology in a developing country were analyzed. Data were collected from literature and interviews in Nyenga, a rural area in Uganda. The methods used for collecting data are described in Chapter

2. Chapter 3 is a description of the biogas system at the Nyenga Foundation in Uganda, where the economic assessment and data on critical factors were sampled. The results from literature and fieldwork are presented in Chapter 4, followed by a discussion in Chapter 5. The thesis uses both the term "biogas plant" and "biogas system", where the plant refers solely to the installed plant while the system includes the substrate source, gas stove, and slurry use.

1.3 Technology transfer and strategic implementation

The success of new technologies in developing countries depends highly on the strategies for implementation (Clemens et al., 2018). Success is the achievement of goals and expectations; therefore, relative to each case. The goals have to be accomplished to claim a successful implementation of the system. In many cases, success is connected to the achievement of goals, avoid unwanted outcomes, and keeping the system operational over a longer time. The strategies that are created and planned should enable success by addressing the critical factors. Kumar et al. defined a critical factor as a "key factor that is essential towards success (…)". Earlier research on technology transfer in developing countries has given an evaluation of the critical factors for implementing technology in a developing country (Kumar et al., 2015, Krishna and Walsham, 2005).

Kumar et al. (2015) analyzed the prioritizing of critical factors to technology transfer by using the AHP framework, and the study considers a total of 24 critical factors, grouped in 5 dimensions. The dimensions were; "Relative advantage in economic terms", "Marketing related benefits and forces", "Technical features", "Regulatory concerns" and "Managerial and strategic issues". The study aimed to facilitate a strategic framework and action plan for the implementation of technology and identifying prominent implications. The considered critical factors were technology-independent, and therefore applicable to biogas technology as well. However, the implementation of new technology demands more than economical and technical concerns, as the habits of people and their mindsets decide the future for the new systems (Corsi et al., 2020). According to Corsi et al. (2020), the social factors of sustainable development are often less addressed or entirely neglected. Without a complete consideration of all existing elements, Khabiri et al. (2012) argue that successful technology transfer is impossible, which makes the technology implementing a time-demanding and complicated process.

The benefits and usefulness of technology are crucial to see a successful implementation for individual households, societies, and nations. The United Nations' third synthesis report builds a solid foundation to find the technologies desired in developing countries (United Nations, 2013). The UN had a project considering technology implementation in developing countries, where the participating countries created a technology needs assessment (TNA). Included in the TNAs were the sectors that needed most development and the technologies evaluated to be useful. The technologies were divided into two categories; technologies for greenhouse gas mitigation, and technologies for climate change adaptions. Technologies from both categories are necessary to manage the development of nations within the frames of sustainability. With a basis in the UN's report, targeted aid is possible to create to the participating countries or nations in similar situations. To help the 31 participating countries with making their TNA reports, the UN provided a handbook to use as a guide. The participating countries then made an Analysis of Barriers and an Enabling Framework Report based on their TNA. The strategical method from the UN provided results that are significant for the way forward considering technology transferring and strategy of sustainable implementation.

1.4 Studies on biogas plants in developing countries

Researchers have studied biogas' potential, barriers, and challenges in several developing countries during the last decade (Roopnarain and Adeleke, 2017, Wassie and Adaramola, 2019, Surendra et al., 2014). The studies have mainly focused more on the national potential of biogas, the requirements of the technology, and the prominent challenges (Clemens et al., 2018). It is essential to direct the focus towards the individual biogas systems and the situation of users to evaluate the viability of biogas plants. Although biogas plants have many benefits, several user barriers need addressing. The biogas technology's barriers are sorted into different categories; economic, technical, environmental, cultural, social, and institutional (Wassie and Adaramola, 2019, Surendra et al., 2014, Patinvoh and Taherzadeh, 2019). Within these categories, the researchers have found some differences in the challenges and possible solutions. The barriers concern both individual users and the nation's ambitions of reaching sustainability goals.

The biogas systems have a high upfront installation cost, which is a significant barrier for many in developing countries (Roopnarain and Adeleke, 2017). Also, Patinvoh and Taherzadeh (2019) argue that with only a few technical experts, the cost of technical service stays high. Developing countries usually do not have many secure financial loaning opportunities, and some of the financial institutions do not wish to prioritize biogas technology, which makes it harder to receive a loan (Patinvoh and Taherzadeh, 2019). Evidence from Uganda shows that only a small percentage of biogas owners received a loan to build their plants (Clemens et al., 2018). The most typical digester types are the fixed-dome and the floating-drum types, which both are immobile and presume that the biogas owner also owns the land. A biogas plant is a substantial investment, and significant investments to a property are not often made by people who lend the property. This implicates that the lacking ownership feeling of the property is a barrier to the implementation of biogas plants at households.

The technical barriers described are associated with a lack of technical knowledge by users, not adequate service and maintenance available, and an insufficient quality standard of digesters. Furthermore, developing countries have less developed infrastructure, which complicates the successful implementation of technologies like biogas (Patinvoh and Taherzadeh, 2019). Wassie and Adaramola (2019) argue that the misunderstanding of "one size fits all" is one of the significant barriers for biogas plants, as the importance of installing an appropriate technical system for the area and household is overlooked. The biogas plants have to match with the substrates, area, and user. When local factors are not considered, it leads to a slow or no adoption of the technology.

Resource availability can be difficult in some places or countries, as lack of enough substrates, water, or a too cold climate during some parts of the year, which inhibits the production of biogas (Patinvoh and Taherzadeh, 2019). Several dis-adoptions of biogas digesters were caused by loss of livestock due to financial reasons (Wassie and Adaramola, 2019). In the African countries, it is common to have the cows grazing during the day and stabled at night (Roopnarain and Adeleke, 2017). It might be necessary to keep the cows inside most of the day to get enough daily input for the plant. Stabled cows need more feed, which will increase the costs of the household and can become a challenge economically and practically. The slurry from the digester can also be a problematic element considering the transportation and application on the agricultural lands (Patinvoh and Taherzadeh, 2019).

The social and cultural barriers are connected to information sharing about biogas' possibilities, social taboo of using manure, and a food culture adapted to cooking with firewood. In Ethiopia, for instance, several biogas systems were abandoned due to difficulties with cooking their traditional bread on biogas stoves (Wassie and Adaramola, 2019). Cooking with biogas is quite different from firewood, and the production of gas is dependent on the amount and quality of the substrates. The traditional meals may turn out different with this way of cooking, which can be an unwanted effect for the locals. According to Clemens et al. (2018), it is common in Uganda to use biogas to boil water or to cook light dishes at lunch, while firewood is still used for the food that needs longer cooking time. Reasons could be a lack of experience with gas stoves or a gas production too low for their needs. Several biogas owners in Uganda are still using firewood, although in a smaller amount than before (Clemens et al., 2018).

Information sharing and record keeping are often neglected but yet essential factors to the implementation of new technology (Roopnarain and Adeleke, 2017). Wassie and Adaramola (2019) found a lack of awareness and experience sharing platforms as significant barriers to the adoption of biogas digesters and leads to a reduced feeling of ownership from the users. By sharing knowledge and experience, it is easier to learn from the past instead of repeating the same mistakes.

The implementation of biogas systems cannot be successful without educating users and make support services available (Patinvoh and Taherzadeh, 2019). When the users know their system better, it is more likely that the operation and necessary maintenance will be sustained. Lack of sufficient training on the biogas process makes it difficult for the user to combine the biogas technology with the existing agriculture (Patinvoh and Taherzadeh, 2019). The training of users must include substrate usage, correct gas use, and slurry use, in addition to maintenance and solutions to typical system troubles. Patinvoh and Taherzadeh (2019) argue it would be optimal with training in both short term and long term with follow-ups on the operation of the biogas system.

The institutional barriers are mainly concerning the lack of necessary policies that promote renewable energies like biogas plants (Wassie and Adaramola, 2019). One possible measure from the government is the implementation of feed-in tariffs (FITs) to ensure sales of renewable energy at a sufficient price (Roopnarain and Adeleke, 2017). Other possible policies can be subsidies for installation costs and tax incentives. A common problem is imported technologies that do not match with the local situation (Patinvoh and Taherzadeh, 2019). It is decisive that the government support research and development between universities and industries. This will strengthen national development and create technological solutions that match the local situation. According to Roopnarain and Adeleke (2017), the government of Uganda has had one of the best near-term plans for the commercialization of biogas technology in Africa.

2 Methods

The asked research questions were answered by two approaches. First, a search of published literature from other studies, with emphasis on technology transfer and implementation of biogas technology in developing countries, was conducted. Further on, a field trip to Nyenga, a rural area in Uganda, was completed. The fieldwork was under the aegis of Engineers Without Borders, and the duration time was three weeks. The three weeks in rural Uganda consisted of a systematic review of Nyenga Foundation's newly built biogas plant, informative conversations with other biogas owners, users, and companies.

2.1 Economic assessment

The biogas plant has an assumed life expectancy of 20 years, and the discount rate of the plant was used to estimate the net present value and assumed to be 9% (Trading Economics, 2020). Compared with developed nations, the discount rate is quite high, which makes loans more expensive.

The biogas stoves are assumed to have an efficiency of 55%, based upon available data from a GTZ report (Kossmann et al., 1999). The previously used woodstoves have an estimated efficiency of 15% (Hirsch and Adaramola, 2019). Nyenga Foundation had a newly installed solar water heating system (SWHS), which was going to be used at the new kitchen with the biogas stoves. The SWHS gives an estimated energy saving of 9.9% (Hirsch and Adaramola, 2019). The profitability of the biogas plant at Nyenga Foundation was estimated in two case scenarios;

Scenario 1: Considering the total daily energy use from the kitchen
Scenario 2: Considering the energy savings from SWHS

The profitability estimations of the biogas plant were based on the analysis of economic data from Nyenga Foundation. The costs of the biogas plant were calculated to annual costs and compared with the annual expenses from charcoal and firewood. The costs were exchanged from Ugandan shillings (UGX) to American dollars (USD) with the currency rate from

08.04.2020 of 1 USD = 3 778.59 UGX. It was assumed that the same substrate mix and amount were fed to the digester every day. It was further assumed that all the slurry produced is used as fertilizer. The necessary measurements, volume, daily feeding, the temperature in the digester were measured during the field trip at Nyenga Foundation.

The timesaving of cooking with biogas instead of firewood or charcoal is likely to be significant and could affect the profitability of the plant. During the fieldwork, it was difficult to measure the time saved as the kitchen with biogas stoves were not finished yet. The time-savings are, therefore, not included in the economic assessment but further discussed in Chapter 5.

2.1.1 Input and output of a biogas system

The daily inputs of the biogas system were analyzed and adjusted during the fieldwork at Nyenga Foundation. The IRENA (2016) field guide was used to estimate the substrate amount, the hydraulic retention time (HRT), and the biogas yield. The estimations assumed that the digester was fed with the same substrate mix and amount every day. The estimated gas production includes simplifications of the biogas yield from the substrates. Table 2-1 shows the daily input to Nyenga Foundation's biogas plant and the substrate sources. As the system was new and not wholly utilized yet, it was assumed that ten people were using the toilets every day, although the goal is a higher usage rate.

Table 2-1 Nyenga Foundation's daily substrate-mix

Daily substrate mix	
No. Cows	5
No. Pigs	3
Grass clippings (kg/day)	4
No. People using toilets	10
Water ratio	3:1
Total amount (kg/day)	292

The gas production was calculated with the given equation from IRENA (2016)

$$G = \frac{Y \times V_d \times S}{1000} \qquad (1)$$

Where G = gas production (m^3/day), Y = Yield factor, V_d = digester volume (m^3) and S = initial volatile solids concentration of substrate mix (kg/day).

Nyenga Foundation wished to substitute all bought fertilizer with slurry. The amounts of slurry produced can affect the profitability of the plant by increasing the annual savings of fertilizer. The slurry produced is assumed to be the same daily amount as the substrate mix fed to the digester.

2.1.2 Potential substitution ratio

The energy demand of the Nyenga Foundation is based on the daily use of firewood assumed to be the same as Hirsch and Adaramola (2019). The amount of firewood the plant's biogas production could substitute was calculated as a percentage of the foundation's energy demand. To cover most of the energy demand from biogas was the aim of Nyenga Foundation when installing the biogas plant. The potential substitution of firewood was estimated for both scenarios to find the potential of the plant and Nyenga Foundation's system. The potential savings and avoided costs were calculated from the estimated substitution ratio. By adjusting the estimations of gas production with the stove efficiency, the expected delivered energy from the plant was found. The substitution ratio was estimated by

$$Sustitution\ ratio\ (\%) = \frac{Energy\ delivered}{Energy\ demand} \tag{2}$$

2.1.3 Net present value and payback time

The net present value (NPV) describes the profitability of future cash flows in the present value. When NPV is positive, a project is considered profitable. The NPV was calculated using the equation below:

$$NPV = -C_i + \sum_{t=1}^{n} \frac{C_f}{(1+r)^t} \tag{3}$$

Where C_i is the investment costs, C_f is the net cash flow, r is the discount rate, and t is the period of the cash flow. The discount rate was gathered from Trading Economics (2020) with data from February 2020.

The payback period shows how long time it will take to save the full installation cost by using biogas instead of firewood. The payback period is given by

$$SPP = \frac{C_i}{annual\ savings} \tag{4}$$

Where SPP = payback period and C_i = investment cost.

2.1.4 Risk and sensitivity

The risk and sensitivity of the biogas plant's profitability were estimated based on the net present value. An NPV equal to zero shows how much woodfuel Nyenga Foundation has to save to keep a profitable plant. The payback time when reaching an NPV of zero was also calculated. The NPV and payback time was estimated for both scenarios – with and without energy savings from SWHS.

A sensitivity analysis of the NPV was performed for the factors; firewood substitution, fertilizer substitution, discount rate, and installation cost. The analysis shows how profitability is affected by a percentage change in one of the factors. The NPV for Scenario 1 was used as a basis for the analysis. Since the ratio between Scenario 1 and 2 are constant, the sensitivity analysis will be applicable when considering Scenario 2 as well.

2.2 Literature search

Published literature and reports about the implementation of technology and the effects of biogas plants in developing countries were gathered by using databases from NMBU's access; Oria, Scopus, Web of Science, and Google Scholar. The table below shows the search words used to find relevant articles.

Table 2-2 Search words for published literature

Focus	Theme	Geographical
Implementation of technology	Biogas	Uganda
Technology transfer	Anaerobic digestion	East Africa
Energy transition	Slurry	Developing countries
Barrier identification	Clean cooking	Rural
Challenges		
Prospects		
Renewable integration		

The articles on technology transfer were not on biogas technology, but the provided information on the implementation process in developing countries and critical factors that needs addressing. The articles from the literature search were complimented with reports from the United Nations and Hivos. The UN has published reports and handbooks on technology assessment and implementation in developing countries. Hivos has contributed to the African Biogas Partnership Program who has installed many biogas plants in East Africa.

The literature search showed that the term "technology implementation" is much more used than integration. The articles published with technology transfer as keywords were mostly about IT-services but had some general information on strategies that were applicable. The research done on biogas in developing countries were mostly about the prospects or challenges, and not the strategies of the implementation process. Many of the articles on biogas in developing countries were newly published; most were not older than from 2015.

2.3 Analysis of critical factors from field

The collected data was gathered in rural eastern Uganda, the spring of 2020. The fieldwork intended to find trends of domestic biogas' critical factors in rural areas. From the limited material of 11 biogas plants, it was focused on having qualitative interviews with the participating biogas owners and analysis of how their biogas system worked. The interviews were based on an interviewing guide with topics to discuss, and not fixed questions. The purpose of the interviews was to find factors that promote or prohibits the implementation of biogas technology for users in rural Uganda. The participants were found through the contacts of Nyenga Foundation and Biogas Solutions, the company constructing Nyenga Foundation's biogas plant. The constructors from Biogas Solution were able to arrange interviews with their customers. A qualitative interview with Kakira Sugar Factory was also conducted with a visit to a biogas plant they had installed.

2.4 Participants in Uganda

Table 2-3 shows the participants and sample size from the fieldwork in rural Uganda. A total of eleven biogas plants were visited, and most of the owners were interviewed. The living standards varied amongst the participants, from small sheds to bigger houses. Two of the biogas plants were dis-adopted; one subsidized to a farmer but never used, and one Kakira Sugar Factory had installed for a project in their village. The other of Kakira's plants was a community plant providing gas for six households. Most plants had only one connected gas stove, while Nyenga Foundation's larger plant had four stoves. Some of the households had constructed an additional inlet intended for a future latrine connection, which is presented in the participant table below with "possibility for latrines" in the substrate source column.

Table 2-3 Participants in Uganda

Participant no.	Size (m^3)	Age of plant	No. Stoves	Sub. Source	Phase of operation	Living standard
1	9	7 yrs.	1	Pigs, some cows, and sewage water	Full operation	Big house
2	12	4 months	1	Cows	Full operation	House
3	20	N/A	1	Cows, a possibility for latrines	Full operation	Business farm
4	9	N/A	1	Cows	Full operation	House
5	6	3 yrs.	1	Cows	Barely operational	Small shed
6	6	3 yrs.	1	Cows	Dis-adopted	House
7	9	2 yrs.	1	Cows	Full operation	House
8	4	6 months	1	Cows, a possibility for latrines	Full operation	Big house
9 – Kakira	20	N/A	1	Cows	Dis-adopted	Business farm
10 – Kakira	30	4 months	6	Cows, a possibility for latrines	Full operation	Houses
11 – Nyenga foundation	30	2 months	4	Cows, latrines, pigs, grass clippings	Starting phase	Organization

The focus at each place was to at first let the participants show and tell about their biogas system, and then get Biogas Solutions to tell about their thoughts of the system. The intention was to get an impression of how much knowledge the participants had of their plant and reveal misunderstandings or knowledge gaps. The biogas owners were asked about how it was to use the biogas plant, what had been positive about it, and what was challenging. Some were asked their thoughts on reasons for plant abandonment and why others were hesitant to biogas installation. The biogas owners were additionally asked how they learned about the biogas technology and what their plans for the biogas system were. The questions were adapted to the conversations with relevant follow-up questions. The constructors were included in the interviews to try decreasing potential cultural barriers.

The data collection at Nyenga Foundation's plant was gathering economic costs, evaluating the biogas plant, system, and routines. New routines were established, training of workers was started, and some challenges at the plant were fixed during the fieldwork. Information from conversations with the foundation's workers was used additionally to the results from the participants. The goal was to create an understanding of the technology and establish good routines that would make it possible to continue the daily operation without much help.

3 Technical description of Nyenga Foundation's plant

A biogas plant was recently installed at Nyenga Foundation, localized in rural eastern Uganda. The aim of the installation was to substitute firewood and charcoal for a cleaner and more effective energy carrier. The installed plant is a large domestic plant of 30 m^3, that is going to provide enough gas to cook for the primary school's pupils and all employees. The daily energy demand was estimated to be 130.5 kWh for cooking. The plant is fed twice a day with a daily input consistent with cow dung, pig dung, grass clippings, and sewage from the toilettes. Since the foundation does not have enough cows to feed the digester only on cow manure, the daily input is a mix of various organic waste. By combining several different substrates in a co-digestion, methane production increases beyond each substrate's usual potential (Hagos et al., 2017). Nyenga Foundation also wanted to save money on fertilizer by using the slurry from the biogas plant as a substitute.

3.1 Daily input and substrate availability

The biogas plant was daily fed with the manure from their five cows and three pigs, human excreta was flushed from the six latrines, and grass clippings from their fields are added. The daily input was also mixed with a significant amount of water, as the mixing ratio was 3:1. Figure 3-1 shows the daily input and output of Nyenga Foundation's biogas plant. More water was used in the daily input at Nyenga Foundation than the standard amount, as most people had a 2:1 ratio. The higher water usage is explained by the necessity of much water for the flushing of toilettes and inconvenient system design. Nyenga Foundation is demographically well placed in a wet area where there are vast amounts of water.

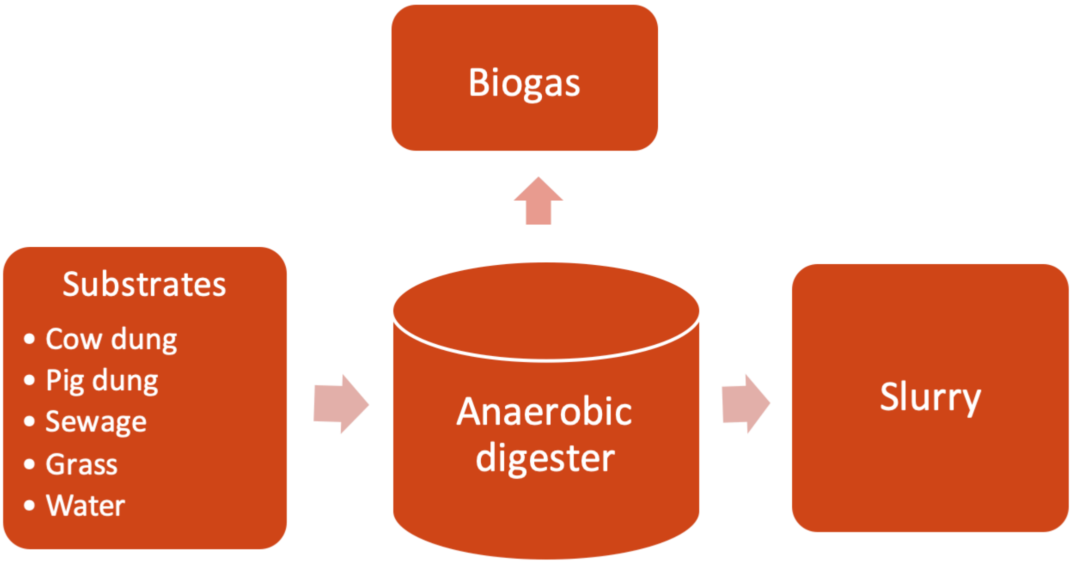

Figure 3-1 Input and output of Nyenga Foundation's biogas plant

3.2 System design

Nyenga Foundation's biogas plant was a continuous flow plant with two chambers, as shown in Figure 3-3. The cowshed and toilettes were directly connected to the biogas plant, whereas the pig dung and grass clippings were brought to the mixing tank every day. All the mixing tanks led to the collecting chamber, which is closer shown in Figure 3-2. The substrates go further from the collecting chamber and into the digester. The gas production in the digester pushes the mix to the expansion chamber. When the gas is used, the mix flows back to the digester and mixes with new substrates from the collection chamber. The overflow goes out in the slurry tank, ready to be used as fertilizer.

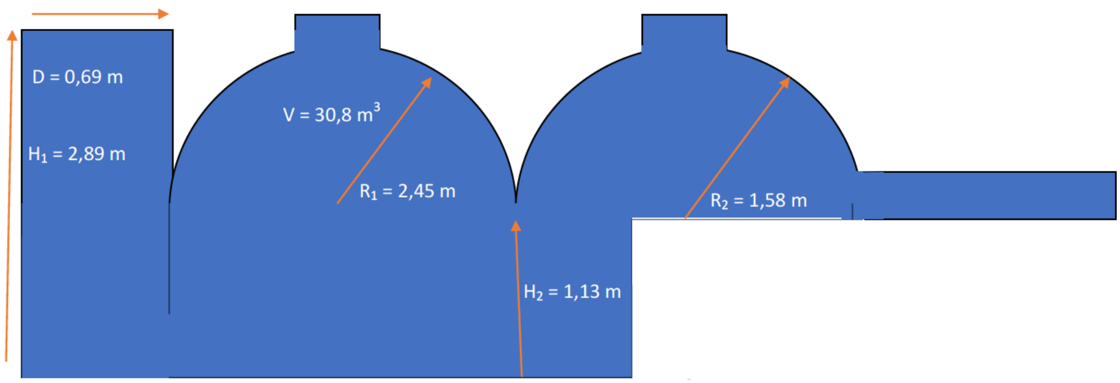

Figure 3-2 Simple illustration of Nyenga foundation's biogas plant

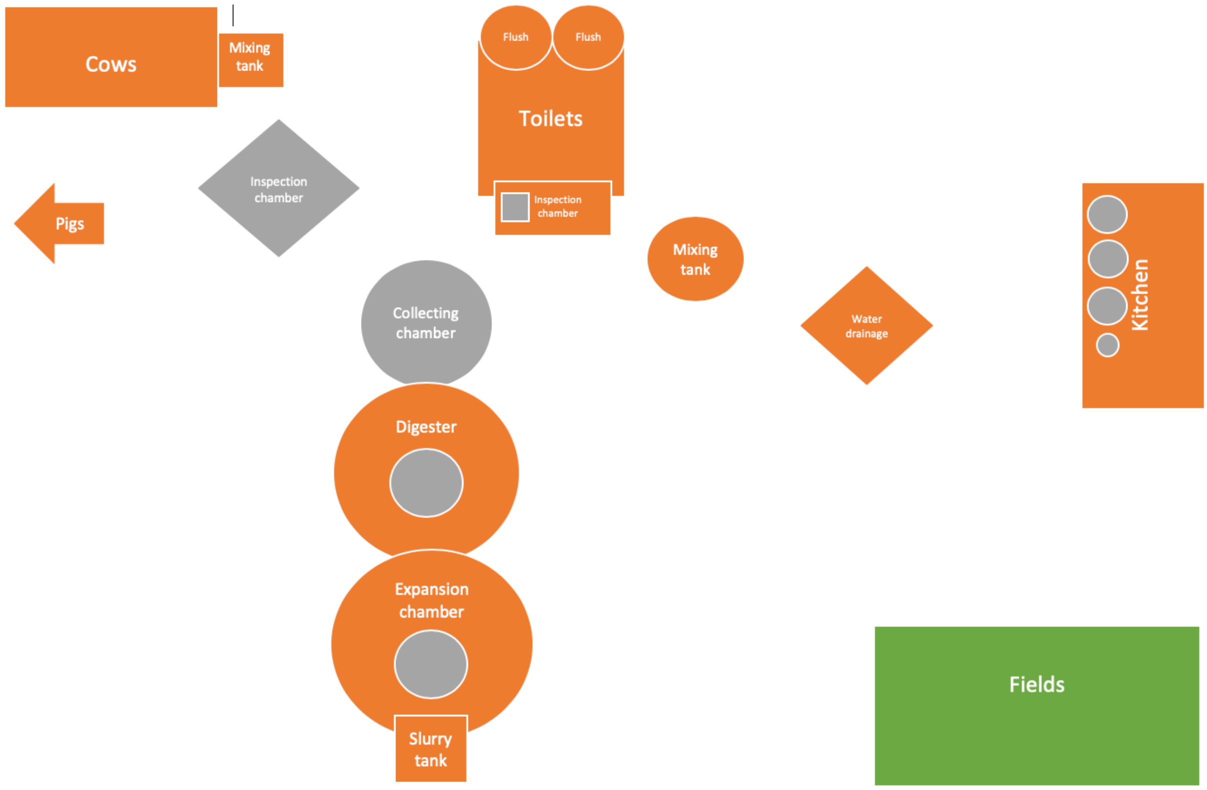

Figure 3-3 Biogas system at Nyenga Foundation

The illustration above presents a simplified version of the biogas system at Nyenga Foundation. The substrates come from cows, pigs, toilets, and fields. As the pig shed is placed further away from the plant, it was illustrated as an arrow. Biogas flows in pipes from the digester to the kitchen, and the slurry is used from the tank and on the fields. The other components of the system are inspection chambers and the vent for water drainage from the pipes.

A new kitchen was built for the biogas system with four gas stoves – three combination stoves and one small gas stove. The combination stoves enable firewood usage in case of low biogas production. From the plant, biogas goes in tubes to the kitchen and stoves. A pressure gauge is installed next to the gas handle for monitoring the gas amounts. A solar water heating system (SWHS) was installed to lower the energy consumption of the kitchen. The SWHS heats 200 liters of water to 60˚C which is then used for further cooking. Based on the calculations of Hirsch and Adaramola (2019), SWHS lowers energy consumption by 9.9%.

4 Results

4.1 Economic assessment of the system

The table below shows the budgeted costs of 2019 from the Nyenga Foundation. The installation cost of the biogas plant was including the expense of constructing the connected toilets as well. The budget was in Ugandan shilling (UGX) but is exchanged to American dollars (USD) with the currency rate of April 2020, where 1 USD = 3 778.59 UGX. A loan has not been considered in this assessment as Nyenga Foundation did not need it.

Table 4-1 Nyenga Foundation's budgeted costs of 2019

Expenses	**UGX**	**USD**
Wood fuel	3 900 000	1 032
Fertilizer	416 000	110
Biogas installation	18 600 000	4 922
Price per kWh	124.5	0.03

The price of wood fuel per kWh was estimated based upon Nyenga Foundation's wood fuel use and cost, repairs and service were not included in the price estimation due to lack of data. The biogas price per kWh was based on the data from Nyenga Foundation as well, with their installation costs, expected life span, and estimated biogas production. The installation cost was also inclusive of the construction of the connected toilettes. The estimated LPG price was based upon the installation cost given at Dignited.com (2020) and Nyenga Foundation's energy demand. The electricity price in Uganda was collected from Global Petrol Prices (2020). The results are presented in Table 4-2 below and show that biogas has the lowest price in USD/kWh with wood fuel as second cheapest.

Table 4-2 Comparison of fuel prices in Uganda

	Price (USD/kWh)
Wood fuel	0.03
Biogas	0.01
LPG	0.35
Electricity	0.18

The estimated energy demand is shown in the table below. The fuel demand was assumed the same as Hirsch and Adaramola (2019) found the year before for a school year at Nyenga Foundation of 240 days. The energy delivered was corrected for the efficiency of the woodstoves. The estimated energy demand was 131 kWh/day, and with the consideration of the SWHS, the energy demand was 110 kWh/day.

Table 4-3 Estimated energy demand at Nyenga Foundation

Energy demand	
Cooking fuel yearly (kg)	36 000
Cooking fuel yearly (kWh)	208 800
Energy delivered (kWh/yr.)	31 320
Daily energy demand (kWh/day)	131
Daily energy demand with SWHS (kWh/day)	110
Annual energy demand with SWHS (kWh/yr.)	26 406

4.1.1 Input and output of the biogas system

The biogas production was estimated with the assumption of the daily input fed to the digester was 280 kg, with the substrates coming from the sources listed below. It was assumed that the daily slurry amounts are equal to the daily input. The hydraulic retention time (HRT) in the digester was estimated to be approximately 107 days. The optimal HRT for substrates, including human excreta, is 60 days (Mang and Li, 2010), in which Nyenga Foundation's plant is well above. A long time in the digester will dissolve the substrates even more, which is beneficial for the bio-waste, which is rich in fiber.

Table 4-4 Input and output of biogas plant

Input	**Amount (kg/day)**
Cow	50
Pig	15
Human	2
Grass	3
Water	210
Total daily input (kg/day)	280

Output	
Slurry (kg/day)	280
Biogas (m^3/day)	3
Energy delivered from biogas (kWh/day)	109
Annual energy delievered (kWh/year)	26 192

4.1.2 Potential substitution ratio

The possible substitution rates were estimated based on the annual energy demand and the annually delivered biogas for the two scenarios, presented in Table 4-5 and Table 4-6 below. It was assumed that Nyenga Foundation would use all the potential delivered gas in both scenarios as the gas amounts were lower than the annual energy demand. The estimations show that with SWHS, Nyenga Foundation would substitute 93% of their firewood usage. These results show that out of the 240 school days, Nyenga Foundation would have to use firewood only 17 days.

Table 4-5 Estimated substitution ratio for scenario 1 – the plant's potential

Daily energy demand (kWh/day)	131
Annual energy demand (kWh/year)	31 320
Substitution ratio	84 %
Days without biogas for cooking	39

Table 4-6 Estimated substitution ratio for scenario 2 with SWHS

Daily energy demand (kWh/day)	118
Annual energy demand (kWh/year)	28 219
Substitution ratio	93 %
Days without biogas for cooking	17

4.1.3 Net present value and payback time

The net present value (NPV) and the payback time (SPP) for scenario 1 and 2 are shown in Table 4-7 and Table 4-8. The estimations are based upon the results from Table 4-5 and Table 4-6, and the budgeted costs of wood fuel. The annual savings were used to determine the profitability and payback time of the plant. In the case of Nyenga Foundation, the potential savings have been estimated by the potential savings of wood fuel and fertilizer expenses. The NPV and SPP were estimated for both scenario 1 and 2.

Table 4-7 NPV and SPP of the biogas plant at Nyenga Foundation

Scenario 1	**Expense (USD)**	**Substitution rate (%)**	**Sum (USD)**
Fertilizer	110	100 %	110
Wood fuel	1 032	84 %	863
Sum			973

Payback time (yrs.)	5.1
Net present value	3 962

Table 4-8 NPV and SPP with energy savings from SWHS

Scenario 2 – with SWHS	**Expense (USD)**	**Substitution rate (%)**	**Sum (USD)**
Fertilizer	110	100 %	110
Wood fuel	1 032	93 %	958
Sum			1 068

Payback time (yrs.)	4.6
Net present value	4 827

The first scenario presented was based on the energy demand without considering the solar water heating system. The second was adjusted for energy savings from the water heating system. The tables show that with the solar water heating system installed, the payback time will be shorter, and the profitability increase.

4.1.4 Risk and sensitivity

The calculated profitability of the biogas plant at Nyenga Foundation depends on the firewood and fertilizer substitution level, as these are the annual savings of using biogas. When the net present value is above zero, the project is considered profitable. The amount of firewood Nyenga Foundation had to substitute in order to reach profitability was estimated with the assumptions of the foundation saving 100% and 0% on fertilizer. The results are presented in Table 4-9 and Table 4-10.

Table 4-9 NPV equal to 0 with fertilizer substituted

	Expense (USD)	**Substitution rate (%)**	**Sum (USD)**
Fertilizer	110	100 %	110
Wood fuel	1 032	42 %	429
Sum			539

Payback time (yrs.)	9.1
Net present value	$-

The lowest acceptable substitution ratio of firewood when 100% of fertilizer expenses were saved, was estimated to be 42% of the original firewood usage. The results imply necessary daily firewood save of 63 kg and an annual save of 15 120 kg, to accomplish profitability.

Table 4-10 NPV equal to 0 with no fertilizer substituted

	Expense (USD)	**Substitution rate (%)**	**Sum (USD)**
Fertilizer	110	0 %	-
Wood fuel	1 032	52 %	539
Sum			539

Payback time (yrs.)	9.1
Net present value	$-

The lowest acceptable substitution rate of firewood when 0% of fertilizer expenses were saved, was estimated to be 52% of the assumed firewood usage. Nyenga Foundation will have to save 78 kg daily on firewood and 18 720 kg annually in order to reach profitability.

The sensitivity analysis is illustrated in Figure 4-1 below. The analysis shows how the NPV of Nyenga Foundation's biogas plant is affected by a change in certain factors. The steepest slopes have the most significant impact on profitability.

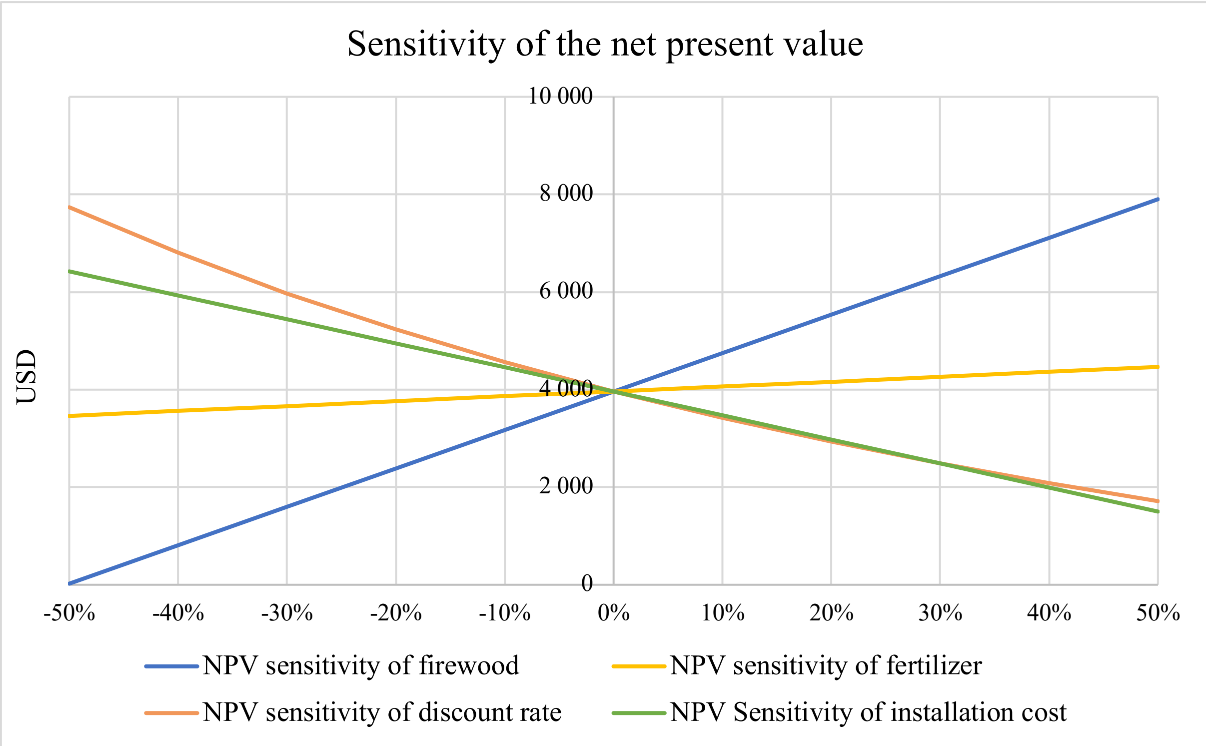

Figure 4-1 Sensitivity of biogas profitability

The most crucial factor of the plant's profitability is the substitution of firewood, as this gives the most significant variation in the net present value. Of the analyzed factors, the fertilizer substitution is the least important to the profitability, whereas the other factors all have a considerable effect. The fertilizer use at Nyenga Foundation is a relatively low cost, which makes the NPV less sensitive to a change. With continuous use of slurry, the soil's health will improve, and the yield from the fields will increase significantly. The slurry can make the biogas plant more profitable than estimated above.

4.1.5 Economic results

The economic assessment was based upon the given assumptions and available data from Nyenga Foundation and showed that their plant would be profitable with a payback time of approximately five years. These estimations do not include time consumption, although the efficiency will enable time savings in the kitchen. Still, the production of biogas may give extra work for the cow keeper, and this extra time is not included in the profitability estimations. The sensitivity analysis shows that factors the profitability is most sensitive to, is the amount of gas produced and the amount of firewood bought. This implies that for the biogas plant at Nyenga Foundation to be profitable, the gas produced has to be used, and the firewood purchase has to decrease. Uganda's average discount rate of 9% is quite high compared with other developed nations. The high rate makes it more crucial for the profitability to have a short payback time, and the sensitivity analysis shows that the discount rate affects profitability considerably.

4.2 Analysis of critical factors

4.2.1 Literature search

When implementing technology in a country, several critical factors need to be addressed to achieve success. Published studies have found the most critical factors to an implementation process in developing countries. Although the factors are not technology-specific, many aspects are still highly relevant to biogas technology adoption. The studies published on biogas in developing countries have emphasized the potential benefits and challenges of the technology, and not as much specifically on the implementing process and strategies. The success of implementing any technology is dependent on the consideration of all elements; financial, environmental, technical, cultural, social, and institutional.

Many of the published studies found on biogas in developing countries and technology transfer lack a definition of the success criteria. However, the term "success" is used in several studies and of several cases (Wassie and Adaramola, 2019, Roopnarain and Adeleke, 2017, Clemens et al., 2018, Nes et al., 2009, Khabiri et al., 2012). As success is a relative term, the definition in each case should be clarified. When success is claimed on different and unknown grounds, it is difficult to compare studies and learn from the approaches. The success criteria may be essential to using the evidence in adapting biogas plants to similar areas. Krishna and Walsham (2005) have defined success in their study as the accomplishment of two criteria. The first is satisfied when the installed system has been in continuous operation over a set amount of time, and during that time expanded in coverage and scope. Troubles and complications must be addressed to succeed in the operation and expansion. The second criterion is met when most stakeholders have achieved their goals without unwanted outcomes from the system.

A successful technology transferring to developing countries are reliant on a strategic plan that considers many dimensions and critical factors (CF). According to the findings of Kumar et al. (2015), the most crucial dimension to the transferring process is "Regulatory concerns". The top CF in “Regulatory concerns” was found to be “International bodies”, though all of the three CFs within this dimension were ranked as the top critical factors. International bodies are organizations or developed nations that provide developing countries with funds and support. The findings of Krishna and Walsham (2005) say that it is challenging for organizations to keep funding a project over a more extended period of time. As the international bodies are essential factors to the adaptations of new technology, keeping the support is necessary for the complete implementation process. The ABPP reports of 23 – 33% of all biogas plants are abandoned within three years-time (Clemens et al., 2018), which signifies that the first three years to be heavily reliant on sustained support. The next highest-ranked CFs within “Regulatory concerns” from Kumar et al. (2015) were “Government authorities” and “Environmental concerns”. The nation’s government and policies are crucial to the adoption of new technology and the development of the country. The importance of policies to support and promote biogas technology, in particular, is emphasized by Roopnarain and Adeleke (2017) as some of the most important facilitators for implementation. The authors further emphasize the importance of a local adjustment to the policies, as the same policies might not give the same results in all countries or regions. The policies applied should go through a carefully executed planning process to ensure feasibility in the area.

The second-ranked dimension in the research by Kumar et al. (2015), were “Relative advantage in economic terms”. “Higher margins of profit” was ranked as the top critical factor, whereas “Cost-effectiveness” was the lowest ranked within the dimension. This can signify that it is more critical to increase income per sale than to lower the overall expenses. Within “Technical features” in third place, the most critical CF was “Reliability”, which includes a higher demand for technical assistance, quality, and reliability of the product or service (Kumar et al., 2015). The fourth-ranked dimension was “Marketing related benefits and forces”, which had “End-user support” and “Market requirements” as the highest-rated CFs. The last ranked dimension was “Managerial and strategic issues,” where “Commitment” was the highest-rated CF. The commitment is, according to Kumar et al. (2015), within the management’s approach and attitude towards the technology transfer. The dimensions and critical factors prioritized by Kumar et al., concerned mostly the countries or society on a higher level, not the individual users who were more included in the fourth-ranked dimension of “Marketing related benefits and forces”.

Successful implementation of technology is achievable when the focus is technology pull rather than technology push; with the consumer's needs and market, demand is in focus (Jhirad, 1990). This implies the necessity of implementing a technology that has the intention of meeting the current needs of the population. The UN's third synthesis (2013) found that almost all countries participating in prioritized the energy sector for mitigation technologies, and biogas technology were one of the highest-rated. The prioritized climate change adaptation technologies from the UN's third synthesis concerned the agricultural sector and crop management. The prioritized mitigation and adaptation technologies both promote domestic biogas plants. The nutrients from the slurry will increase health and resilience in the soil and contribute to climate change adaptation.

In the African Biogas Partnership Program, a program push was tried in the first phase to create a market for biogas technology (Clemens et al., 2018). The focus was then changed in the second phase to a "market pull" strategy, as Jhirad recommends. The ABPP targeted the producers and upstream actors with incentives, instead of the consumers. The shift of focus in the second phase, made the program go from introducing technology to focus further on how the whole biogas system could take part in the local society.

Learning from mistakes and try again when implementing technology is essential to achieve success when implementing new technology (Krishna and Walsham, 2005). In Africa, there has been lacking records of measures done and results achieved, which is essential information to sustain the implementation and operation of biogas plants (Patinvoh and Taherzadeh, 2019). Record keeping of tried approaches and the results are essential data for further improvements of the biogas technology. Assessments of the already built biogas plants, both operational and abandoned, can promote learning and improvements to make local adaptions of the technology (Patinvoh and Taherzadeh, 2019). By sharing methods, results, and experience, learning of both technology and system can increase (Roopnarain and Adeleke, 2017). The shared knowledge will promote improvements and adjustments that could be crucial to success or local acceptance. In a technology transfer to a developing country, the most critical shift is knowledge (Khabiri et al., 2012). When the user owns all the knowledge of the technology, the transfer can qualify as complete. Communication between parties, organizations, and nations is vital to keep until all knowledge is transferred.

When the recipient country gains all the knowledge of the technology, it is possible to make local adjustments for achieving a viable implementation with support for the users. In cases with biogas systems, several plants have been abandoned due to problems not fixed due to unsolved problems. A high rate of abandonment creates a bad reputation for the biogas systems and can lead to a halt in the implementation process (Roopnarain and Adeleke, 2017). As a part of the ABPP's second phase with market pull-focus, it was made more beneficial for the producers to enable end-user service, which would tackle some of the abandonment issues. Service centers were established for customer support, which would call the new and old biogas users for follow-ups.

The relationship between research and the marketplace in developing countries is often weak, which complicates the development of the country (Jhirad, 1990). A strengthened relationship between research institutions and the commercial market can lead to design changes that are more cost-effective and beneficial for the local area, which the studies of Patinvoh and Taherzadeh (2019) emphasize as essential to overcome the technical and economic barriers. The technical information will then be known by the locals, combined with the local adjustments; this will increase the probability of success. By including biogas in national education, the knowledge will spread in the population and lay the groundwork for further development and viability. Patinvoh and Taherzadeh (2019) argue that the government should provide this as a part of the education program.

When a new technology is implemented, an upfront obstacle is the need to change the existing systems and processes (Krishna and Walsham, 2005). The system changes that biogas plants make are the need for stabling cows, which demands the building of a cowshed and obtain feed. In many African countries, it is more usual to have free range cows to lower costs, but this will complicate and pollute the collection of dung for the plant. The implied extra costs and delays of finished installation can be challenging to justify to poorer countries, argued by Krishna and Walsham (2005). When the second phase of the ABPP's program was implemented, the focus shift made the program go from introducing the biogas technology to focus on the plant as a part of a more extensive system by linking people together and more. One of the barriers found in the studies of Wassie and Adaramola (2019) was the lack of platforms for biogas owners or interested parties to gain knowledge and share experience. These platforms can enable the sharing of valuable information, experiences, and enthusiasm of biogas technology and system.

The studies of Jhirad (1990) states that developing countries should take advantage of innovations and learnings from other countries and not repeat the same path as they walked before. There are numerous of factors necessary to address in order to manage such a grand leap in development, although it is beneficial. Corsi et al. (2020) argue that the technology and the transfer process should keep the sustainable objectives in focus to secure sustainable development. The technologies have to be environmentally friendly, and the process of implementing them in developing countries have to be in favor of the inhabitants of the vulnerable locations. Additionally, the mindset of people will have to change in order to make the development viable, which strengthens the importance of the social factors to technology transfer. The studies of Corsi et al. (2020) show that the social impact is rarely mentioned in the published research, although it is very much an essential factor. For biogas plants, one of the most-mentioned social barriers is the social taboo of handling the animal and human waste in the biogas system. In several East African countries, the use of fertilizer is not too familiar yet, which creates an even bigger hesitant of using the slurry (Roopnarain and Adeleke, 2017).

The United Nation's third synthesis (2013) reported of all the 31 participating countries made TNA reports on adaption to the climate changes, and 29 made reports on the mitigation of GHG emissions as well. All of the participants reported involving stakeholders, but only a few involved stakeholders from the finance community. For GHG mitigation technologies, the economic and technical barriers were reported to be amongst the most pressing, which is in line with findings from studies on biogas technology in developing countries. The most mentioned problem concerning the economic factors were inappropriate financial incentives and disincentives. In ABPP's second phase, subsidies of plant installation were removed, and as a result, affordability became a significant barrier to the adoption of biogas technology. The technical barriers were mostly concerning inadequate standards and certification of the installed plants.

4.2.2 Results from fieldwork in Uganda

A total of eleven biogas plants were visited during the fieldwork, and the results are presented in

Table 4-11 below. Among the participants, most plants were installed within the last three years, and two of the plants were abandoned altogether. The participants were mostly the owners of the plant or employed workers. Although plant no. 6, shown in

Table 4-11, was described by participant 5, who was the neighbor, and the constructors in Biogas Solutions as the owner was not around. The biogas plant was abandoned because the owner had been told to move a short time after installation. Three years later, the owner had not moved, and the biogas plant was still left unused. Plant no. 9 was owned by the Kakira Sugar factory and had been a part of a project for providing the village with biogas from the factory's dairy farm. The gas was filled in gas bags and transported to the village for usage. The system was abandoned due to impractical bags and community members fearing the bags would explode during transport. The 11th plant was at Nyenga Foundation, which was more carefully analyzed. Most of the participants had bought the biogas plant themselves, but two of the plants were financed by Kakira Sugar Factory, and a nongovernmental organization financed two others. Among the sample of participants, the plants who were sponsored or substituted had the most problems. Two of them were dis-adopted, and the other two had significant challenges. The "success"-column in

Table 4-11 shows if the participants found their biogas plant successful, which most participants did. The biogas plant at Nyenga Foundation was too recently started to evaluate the success of the installation. Instead, the critical factors of the start-up phase were analyzed.

Table 4-11 Results from participants in Uganda

No.	Success in their opinion	Benefits	Challenges	Financed	Understanding of technology
1	Yes	Cleaner and faster cooking Easy	The slurry was heavy work	By household	Yes
2	Yes	Cleaner and faster cooking	Too much cow manure and slurry Heavy work feeding digester	By household	Yes
3	Yes	No need for firewood transport Easy and fast cooking	Too much cow dung	Business	Yes
4	Yes	Cleaner and faster cooking Less damage on kitchen Cooking inside	Too much slurry challenging to get rid of	By household	Yes
5	Yes	Less work Easier cooking No smoke	No cows Had to buy water	Subsidized plant	Uncertain
6	No	-	Never used	Subsidized plant	-
7	Yes	Cleaner and faster cooking Less damage on kitchen Cooking inside	Needed one more cow	By household	Yes
8	Yes	Clean, cheap, easy and fast cooking	The slurry was heavy work	By household	Yes
9	No	Alternative provision of biogas for households	Inconvenient gas bags and utilization	Company bought	Yes
10	Yes	Management of cow dung Easy cooking	Too much slurry Over-feeding No pressure gauge	Company bought	Uncertain
11	Just started	Substitution for firewood and charcoal Faster cooking Cleaner cooking	Routines Unfinished kitchen Impractical plant design Substrate amount	Company bought	Trained during fieldwork

The most seen and mentioned benefits and bottlenecks to domestic biogas production are listed below in Table 4-12. Some of the bottlenecks are not necessarily negative factors, as this will vary amongst the biogas owners and their capacity. The pros are compared to the participants' earlier cooking stoves, which used charcoal or firewood.

Table 4-12 Benefits and bottlenecks of domestic biogas

Benefits	Bottlenecks
Faster and easy cooking	Substrate and water availability
Clean cooking	Slurry amounts
Money-saving	Complex system
Fertilizer for field and gardens	Demands knowledge and training
	High installation costs

4.2.2.1 Benefits of transferring to biogas

All the participants with operational biogas plants were very pleased with using biogas for cooking and mentioned several benefits caused by the transfer from traditional woodstoves. Time-saving was the most highlighted benefit as several participants expressed happily, “it takes only one hour to cook beans”. All participants showed how to turn on the gas stove and explained how easy it was to cook on the stove and how to monitor the gas available from the pressure gauge. According to the participants, the food did not taste different from before. Participant no. 4 and 7 were pleased that they did not need maintenance work at their kitchen anymore due to the absence of damaging smoke and soot. Some had moved their kitchen inside, from having it in a shed outside, due to the absence of smoke. Participant no.1 and 3 cleaned less kitchen wear because of less soot from biogas stoves than woodstoves. The health benefits of smoke absence were also appreciated among the participants. All of the participants said they saved money on the use of biogas, as firewood and charcoal had been a significant expense before installation. Only a few participants had visible firewood and charcoal stacked, and most said they used mainly or only biogas. Additionally, the slurry gave good yields in their gardens and fields, which increased their income. Participant no. 3 had a big farm that grew elephant grass for their own 80-100 cows, where the slurry had increased their production significantly as it was used regularly on the fields. Participant no. 7 had ambitions of growing organic vegetables only and took advantage of all the slurry produced from her plant, which had given a great result.

4.2.2.2 Substrate and water availability

The written information given by Biogas Solutions described only the possibility of using animal dung, and mainly cow dung. Most of the participants used only cow dung, only a few used pig dung and just Nyenga Foundation used human waste as substrates for the biogas plant. Among the participants, none had knowledge of the benefits of using other bio-wastes as food waste or crop residues. Most had only small amounts of food waste, which went to the animals. Some of the participants had tried using bio-waste earlier, but it came out of the digester is too big pieces, which made them stop using it. At Nyenga Foundation, the grass was cut on the lawns and football field, which was included in the daily input to the plant during the fieldwork. Two of the participants with operational plants had too little substrate for their plant and could benefit from using other substrate sources to increase the daily input too. The other participants with an overflow of slurry had mostly too many substrates, which resulted in overfeeding of the digester, as previously mentioned. The amount of substrate did not correspond with the chosen size of the digester, as they could benefit from having a larger plant. In most participants' areas of living, water was not a pressing issue, although the substrate mix demands much water. One of the participants used wastewater separated from their pig shed to save clean water use.

4.2.2.3 Slurry amounts

One of the most evident problems seen during the fieldwork was the incorrect feeding amount of the digester. Many of those who had a lot of substrates available, overfed their digester and had a continuous over-flood of slurry. From the opinions of the constructors and the smell of the slurry, some gas potential was left in the overflow. All of the participants who had slurry used it on their gardens or fields, but of those with too much slurry had difficulties with getting rid of the amounts they did not use themselves. Some of the participants tried selling the slurry, and others gave it away for free. However, they all experienced much hesitance among neighbors that were skeptical about using slurry on their plants. Two of the participants said people were most skeptical about using slurry from pig dung or human waste, though the last one was not too common in the area yet. One of the participants said that people were also skeptical of buying vegetables and fruit from them when they knew that slurry was used. The benefits of using slurry as fertilizer and soil improvement for plants and crops were well-known to the participants, and the slurry had given their gardens and fields good yields.

4.2.2.4 Complexity of system

The biogas plant is a part of a more extensive system and demands strategic planning in order to achieve a manageable workload. If the substrates are localized far away from the plant, the daily operation of the plant will take more time and effort than necessary. As the slurry is quite heavy and is going to be used on gardens and fields, the slurry tank should be placed in a way that makes utilization of slurry as easy as possible. All these parts of the system need well-executed planning to make the daily operation effective and keep the time-saving benefit of using biogas instead of firewood and charcoal. Among the participants, two managed to plan their systems to such extent they could take advantage of all parts of their systems. They had sufficient amounts of substrates and gas, and all the slurry was used. Other participants did not manage to utilize all their substrates or slurry, which became a problem for them. However, some participants had less capacity to use on their biogas system; for instance one participant who cared for her two kids and sick mother, managed the cows, house, and had a job.

Some of the participants had impractical solutions that could have been avoided if the system planning was executed more detailed, like choosing an appropriate area for the plant. One of the participants had started to build a mixing tank by his cowshed, but when the constructors came to build the plant, it was not possible at the user's intended place. The result was that he had to carry cow dung from the cowshed to the mixing tank ten meters away, which resulted in an increased workload of heavy lifting. At Nyenga Foundation, a similar case was evident where the inclusion of pig dung was not planned. The biogas plant was built together with the cowshed and toilets, while the pigs stabled were further away. The substrate contribution from the pigs became a challenge as bringing the pig dung to the biogas plant increased the workload of the employees and was forgotten often.

In cases where the system was not too well planned, the daily workload was heavy and took time. The difference between the participants seemed to be whether they had installed the biogas plant solely for the cooking gas, or if it was installed to be a part of a bigger system. For those who installed the plant mainly for cooking gas, the slurry seemed to be a residue product instead of a resource in itself. Since the market for slurry was quite weak, it fast became a problem. The weak market demand for slurry made system planning seem even more critical to avoid problems or lost income. For some of the participants, it seemed to be challenging to allocate time and effort to plan their biogas system to be effective and optimal. Some could not plan a system that took full advantage of all the plant's potential benefits.

4.2.2.5 Plant design

The plant at Nyenga Foundation was planned as Figure 4-2 shows, without a collecting tank between the mixing tanks and the digester. The collecting tank was built of unclear reasons, and the field trip revealed it to be a constraint for the system as the mix stayed in the chamber too long and started to produce gas there instead. The gas production in the collecting tank was not possible to utilize and escaped in the air instead. The design of the system makes unwanted gas escape to the air a possibility. The collecting tank contributed to slowing down the substrates on its way to the digester, which quickly led to clogging or dried out substrates. A higher ratio of water in the substrate mix helped to keep a steady flow. The adding of grass clippings had its problems because of the high probability of clogging. The system complications gave the workers at the plant more to do and was a drawback in their daily workload.

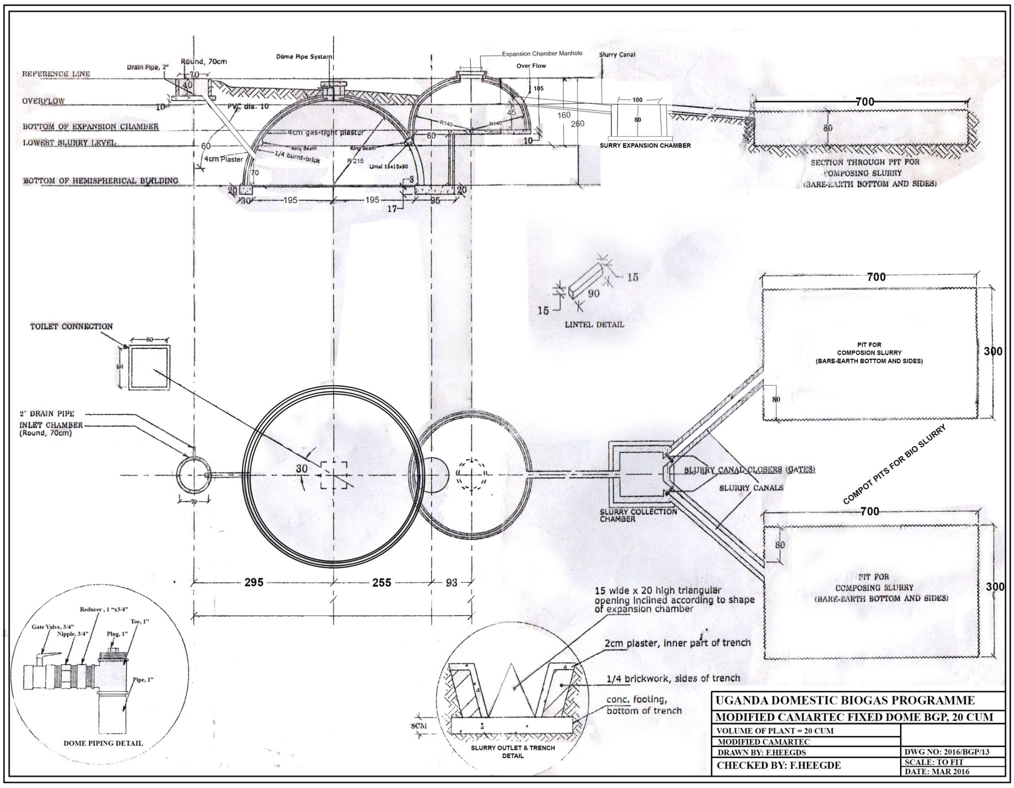

Figure 4-2 Nyenga Foundation's planned biogas plant

4.2.2.6 Knowledge and training

The two participants highlighted above with well-planned systems also had additional knowledge of the biogas technology from either their own higher education or family members with higher education. Still, most of the participants who were costumers of Biogas Solutions had vast knowledge in the production of biogas. The participants had a suitable mixing ratio of substrates and water, and all of them said they mixed to a "porridge". The metaphor seemed to work well as they all were confident in the feeding of the plant, independent of how long they had used their biogas plant. They also showed a great understanding of monitoring the gas pressure; when it was sufficient for cooking and when it had to produce more. The only comparison to Biogas Solution's customers were the two plants owned by Kakira Sugar Factory, where only one was still in operation. This plant lacked a pressure gauge and struggled with overfeeding. The participant who operated the plant did not share the same knowledge as the other participants. From the conversations with the participant and the Kakira employees in charge, it seemed that the training had been less than the Biogas Solution's costumers had received.

Biogas Solutions joined the visits to the participants, and most used the occasion to ask questions to the constructors. Moreover, the constructors had feed-back to everyone about the feeding of their plant or slurry usage. Biogas Solutions explained that they usually did not visit their customers if they were not called for something particular, but if nearby, they sometimes stopped by. They also arranged some connections and meetings between biogas owners. Participant no. 1 thought a reason for the abandonment of biogas plants was that people just waited for the constructors to show up if something needed repairs, instead of calling for service. Most of the plants constructed by Biogas Solutions had engraved date of installation and service phone number on the lids of the plant to make it accessible when needed.

Some of the participants had pamphlets or informational brochures on how to maintain a biogas plant and troubleshooting guides. These had been provided by the constructors if they had them. Possible substrate sources were lacking from the pamphlets, as some of them did not include the use of dung and mixing proportions either. The slurry was promoted as a fertilizer, animal feed, and a pesticide to spray on plants. The participants who had these pamphlets used only cow dung for biogas production. Some of the participants expressed concerns about the safety of handling the slurry, as they mainly used their hands to mix the input. One of the participants said that people were hesitant to install biogas plants because they did not want to get their hands dirty. The hesitance was especially concerning the use of human waste and pig dung in the substrate mix. Information concerning safety and possible health issues were not widely known and would be beneficial to distribute.

Many of the participants got familiar with biogas technology and received the contact information of the constructors through other friends with biogas plants. The participants that were asked all said they lacked a platform for sharing knowledge, experience, and troubles with biogas plants. One of the participants thought that the church could be a right sharing place for biogas systems as most people went there every Sunday. Participants no. 1, who had a degree in animal science, used her plant and knowledge to give tours to students from a nearby university.

4.2.2.7 Shared biogas plants

The high installation costs of biogas plants can make it difficult for people to afford the construction without subsidy or other financial mechanisms. For some, it is an excellent alternative to be a part of a shared biogas plant, like one of the plants bought by Kakira Sugar Factory. The plant was shared with six households with one designated host responsible for the daily operation of the plant, and the plant was therefore installed on his land. The gas was distributed in pipes that went to the other households. Each household contributed with cow dung for the input and a user-fee to the host. The fee was half the price of the estimated coal use, and the households were therefore pleased with the solution, according to the host and Kakira employee in charge. The plant lacked a pressure gauge, which made it difficult to monitor the production and use of the other households.

Kakira Sugar Factory believed that biogas plants would be ideal for schools than households, as the plants demanded a lot from their owners and were expensive. In the cases of collaborative biogas plants between several households, it could quickly arise conflicts or troubles as the plant was missing a leader or an owner in charge of the system. Kakira Sugar Factory wished to install a biogas plant at their schools for cooking and educational purposes. By including the children in the biogas process, the workload would be easier to manage, and practical biogas education would promote biogas technology in Uganda further. Still, the installation of biogas systems at schools could have their challenges. During the field trip, it became visible that changes in routines and workload can be challenging to sustain. If there is installed a plant that uses human excreta from connected toilettes, as Nyenga Foundation, the toilettes must be flushed a couple of times every day. This task was quickly forgotten, and it seemed to be uncertainty in who had the responsibility of flushing. Other informants have also reported problems in delegating the responsibility of flushing as many forget or neglect to do it, believing someone else will carry out their task instead. This reinforces the importance of allocating roles and responsibilities, as many works with the plant in larger organizations like schools.

One of the participants was a businessman who owned a dairy farm with several employed workers. To lower the costs and work with wood fuel, he installed a biogas plant. As the farm had 80 cows, they had a lot more cow dung than the plant of 20 m^3 needed. Some of the excess dung was sold to other biogas owners, for instance, to Nyenga Foundation. The farm worked like a well-oiled machine with workers certain of their tasks and the execution. The daily input was mixed in a ratio of 2:1 with water, and both the gas and slurry were used every day. By the looks of the farm, the biogas system seemed to be a good fit, and the workers were all pleased with it. The cook was in particular happy with using the gas stoves compared with the previous wood stoves, as it was time-saving and cleaner.

4.2.2.8 Business potential

One informant from Uganda emphasized that in order to implement new technology successfully, there had to be a business potential. For biogas technology, it could be a sale of either biogas, slurry, or even bio-waste management. If the biogas plant and system could generate an income for households or organizations, the informant argued that it would be easier to invest in the plant as the installation costs are high. By installing a plant for business reasons, it could promote the strategic planning of the biogas system to make it efficient. The findings from the other participants suggest that the slurry is an unstable source of income as the market for it is not yet established, although there is potential.

5 Discussion and conclusions

5.1 Significant results and other studies

The economic assessment shows primarily that the biogas plant of Nyenga Foundation is profitable, which can suggest that the success of the plant more reliant on human factors than economic. It further implies that the user's profit of the biogas plant is greatly affected by the savings from the substitution of wood fuel, costs of installation, and the discount rate. To Nyenga Foundation, the most critical economic factor is to purchase less firewood as these savings increases the profitability of their plant the most. If Nyenga Foundation manages to produce the estimated biogas amount, 84% of the firewood consumption can be substituted under the previously stated conditions. This will give the plant an expected payback time of approximately five years, which is short considering the plant's life expectancy. Since the plant is constructed in the ground, it cannot be sold to another place in case priorities change. The plant should be utilized for at least the full payback time to avoid sunk costs.

During the fieldwork in Uganda, many informants mentioned the high prices of wood fuel and wanted a cheaper cooking alternative. The fuel price estimations show that biogas is the cheapest among the standard alternatives, with firewood and charcoal as the second. Among the potential biogas users, the high upfront installation costs prohibit a shift of cooking methods. The use of biogas for domestic cooking purposes was found to be the most cost-effective alternative considering the whole expected life span. Although charcoal and firewood use a cheaper woodstove, the life expectancy of it is shorter, and the fuel prices are high. The high upfront costs of the plant construction can be a considerable hindering with the few financial mechanisms for loans in most developing countries. The inclusion and later removal of subsidy in the ABPP's phases confirmed this. Local adaptations and education in biogas systems can make it easier and cheaper to install and maintain the plants. Due to the high installation costs, biogas plants could be more profitable at larger farms, organizations, or institutions like schools. According to the constructors in Biogas Solutions, biogas plants for individual households were the most common, not collaborative plants. Under the right management, a collaborative plant could be a more manageable investment. For instance, the plant Kakira Sugar Factory installed with an appointed host.

The keeping of records and learning from experiences, both successful and failures, has proven to be crucial to a broader implementation of new technology or systems. Earlier studies on domestic biogas in developing countries have neglected to include a clear definition of the success criteria. A comparison of different studies can be difficult when it is unknown on what grounds success is claimed. The success criteria defined in the studies of Krishna and Walsham (2005) demand goals to be stated, as success is based on the achievement of goals within a set time-frame. To claim success based upon these criteria, the plant would have to overcome challenges, and expand in coverage and scope. Most goals would have to be achieved, and there should not be any unwanted outcomes. Among the participants in Uganda, many of the plants were installed within the last two years. As the abandonment rate of plants is highest during the first three years, it is arguably too soon for those plants to claim success. Participant no. 1 managed to achieve all of the criteria and could qualify as successful. Nevertheless, three more plants showed great potential of staying viable for a long time as they had per then dealt with all challenges, achieved their foremost goals, and planned expansion of the system. The "successful" plants had managed to plan their system to such extent that they took advantage of their whole system, leaving them without unwanted effects. Based on this trend, it can be assumed that system planning is one of the most critical factors for the viability of biogas plants in Uganda.

The domestic biogas plants are a part of a system that demands knowledge from users to function. Transfer of knowledge and training in the technology has been mentioned as some of the most significant critical factors to the viable implementation of biogas technology, and other technologies in general. The transfer of technology is complete when the recipient owns the knowledge and can utilize it. This implies that when installing a biogas plant, securing that the user knows how to operate the plant and what to do in case of troubles, is an essential part of the implementation. A possible approach could be to distribute more information on how to plan the biogas system and ideas on the outlook.

5.2 Methodological considerations

The economic assessment was executed with data gathered from Nyenga Foundation and assumptions based on Uganda's status. The economic evaluations were based on the installation costs, life expectancy, the potential gas production, and possible firewood substitution. The given installation cost included the construction of the biogas plant and the connected toilets and excluded the costs of maintenance and service due to lack of data. The life expectancy was assumed to be 20 years, as the constructors informed of. The potential biogas yield from Nyenga Foundation's plant was estimated with simplified equations and assumptions of the substrates' methane production. The substitution ratio of firewood was calculated from the estimated biogas yield and assumed energy demand. It may differ from the actual potential, due to the earlier stated simplifications. The costs of biogas plants will likely vary between sizes, constructing companies, the workload necessary for construction, and the saved costs from using biogas instead of the previous cooking alternative. The potential savings from substituting wood fuel were estimated based on Nyenga Foundation's budgeted costs. The costs of a woodstove, repairs, or life expectancy were not included in the estimations due to lack of data. The variations in plant costs and potential savings will affect the possible profitability of each biogas plant. The estimated profitability of Nyenga Foundation's plant may differ from reality.

The sensitivity analysis suggests that the profitability of the analyzed biogas plant is sensitive to a change in the discount rate. The discount rate that was used for the assessment was from before COVID-19's potential effect. It is a possibility that the pandemic has had an influence on the discount rate and could affect the profitability estimations. The budgeted costs received from Nyenga Foundation were converted from Ugandan shilling to American dollars with the currency from April. The values of the currencies and the countries' economies have been greatly affected by COVID-19, which are likely to affect the import of resources to construct a biogas plant. The installation costs can, therefore, increase further. The loss of jobs during the lock-down period will affect the potential buyers a lot and could slow down the implementation considerably.

In the economic assessment, there is not included the potential avoided costs from time-saving by using biogas stoves for cooking. The measuring of potential time saved was not possible to execute as the kitchen was not yet finished. Additionally, the plant was in a start-up phase, which caused some extra work in order to get the routines and plant up and running. Still, the time-saving aspect of biogas use was one of the most mentioned benefits from the field and other studies. It is therefore likely that Nyenga Foundation will receive increased benefits from this, which could also lead to a growth in profitability. The cook at Nyenga Foundation used to fire up the woodstoves two hours before lunch to get the food ready in time. The biogas stoves are likely to shorten the preparation time considerably as they are faster to heat and more efficient for cooking.

The results from the fieldwork are based on the data collected from the small sample size in eastern rural Uganda. All the participants lived close to each other, though in different villages. The results are likely to have been affected by the geographical location, as available resources vary with location in the rural areas and, therefore, also the relevant critical factors to the biogas plant. Most of the participants were customers of Biogas Solutions and which could create a systematic skewness in the collected data with some undiscovered, yet important, critical factors. Additionally, some language barriers were prominent as not all the participants spoke English well. The use of an interpreter or the limited English words spoken could lead to information getting misunderstood or lost in translation. Many of the participants were soft-spoken with not too much elaboration of their plant. Much was described as "good" with no further explanation. As a result, the amount of information obtained from the different participants varied. The constructors arranged meetings and joined the conversations, which could both have benefits of gaining more information without cultural barriers but also that the participants did not necessarily tell about all their challenges. The cultural differences between the participants and the two Norwegian engineers could have a significant effect on the gathered results. Still, many of the findings from the fieldwork have been in line with the published studies. It could signify that the small sample size managed to illustrate some of the significant characteristics of biogas implementation in Uganda, which are also valid for other regions and countries with similar socio-economic structures.

5.3 Implications and way forward

The Uganda Vision 2040 sets a framework that is positive for biogas implementation further on in the future. The vision states first and foremost that it wishes to transform Uganda "from a predominantly peasant and low-income country to a competitive upper middle-income country" (The National Planning Authority, 2013). To enable this development, Uganda has to strengthen many fundaments as infrastructure, energy security, and land use and management. The vision further states in 202. "Due to climate change, emphasis will be on other renewable forms of energy including; wind, solar, and biogas, will be harnessed and promoted. The government will invest in R&D and provide incentives to encourage the use of renewable energy". These statements from the governmental vision open up for a broader commitment to implement biogas technology. Still, these are only goals and not the direct policies, which makes them only "gate openers" for new technology to emerge. Uganda has though managed to offer relatively good short-term prospects for biogas, compared with other African countries. The inclusion of Ugandan people and prosocial motivation where individuals want to contribute to the country's development can be vital for the achievement of Uganda's goals towards 2040.

The ABPP's phases of biogas implementation in East Africa have been both flexible and dynamic, with several alterations along the way. The shifts and changes in their program had the intention of adjusting the program to a more efficient approach, but as Clemens et al. argue, some of the policy changes might have come too rapid, which in turn slows down the adoption rate. If new changes or alterations are initiated too soon, the previous adjustments may not yet have stabilized. The many changes and adaptions throughout the program can indicate that the planning of the program lacked a thorough enough evaluation of the critical factors. There is a big difference in the amount of constructed biogas plants in the East African countries (Clemens et al., 2018), which strengthens Roopnarain and Adeleke (2017) argument that there is a necessity of a country-by-country approach to the implementation of biogas technology. The strategic approach used by the UN in the third synthesis report on technology needs assessment (2013) made the participating countries reveal and address the important critical factors.

ABPP addressed many of the critical factors and barriers to the full implementation of biogas technology in developing countries. The program found that the support from international bodies was crucial for sustaining the implementation process, similar to the earlier findings of Kumar et al. (2015), and confirmed that the high installation costs were a significant barrier to the implementation. The focus shift from program push to marked pull is in line with the suggestions from Jhirad (1990) and promotes a viable implementation for the locals. Still, there have been many abandoned plants during the phases of the ABPP, mostly within the plants' first three years. Among the participants in Uganda, two of the biogas plants were abandoned. One plant was subsidized by an NGO and had never been used, just constructed. The plant is an example of transferred technology but not transferred knowledge, thereby unsuccessful, according to Jhirad (1990). The donor organization had subsidized two biogas plants, where both plants had significant issues. The other one was barely operational, and the participant lived in a small shed. The participant had prior to the installation gathered firewood outside. Since her cows were stolen and she could not afford new ones, she now gathered cow dung outside. Although she was satisfied with the use of biogas, she struggled with finding substrates to the plant, and the gas production was low. The system was seeming to demand more from the participant than she could manage. A more thorough planning phase from the donating organizations could reveal barriers and bottlenecks of the households and avoid problems. Sufficient time-use among the NGOs and other stakeholders are promoted as important factors to success.

Although traditional woodstoves have many adverse effects, it is an already implemented system. It will, therefore, need efforts to substitute for a new technology requiring a new system and new knowledge. Some might not feel comfortable using or have experience with gas stoves. The biogas plant that was never started could suggest that the owner did not have the knowledge to operate or did not see the benefits of using it. These are social factors, which Corsi et al. (2020) found to be often neglected, are essential to see a viable operation of biogas plants without unwanted outcomes. In order to see the widespread implementation of biogas technology, the benefits of installation have to be larger than the challenges. The benefits should be evident early in the process to create enthusiasm, encourage a change of habits, and to sustain the implementation of the technology. This emphasizes the importance of handling the potential challenges that arise early. Follow-ups and end-user services like the ABPP implemented during phase 2 can be very beneficial to increase the probability viability of the biogas plants.

The fieldwork showed that the participants with the most well-working biogas systems had a great interest in their system and sought more knowledge. They planned for all parts of the system, including which crops to produce and possible expansions. When a household can plan and use the whole system, it affects the financial aspect positively as all resources and products of the system are utilized (Clemens et al., 2018). These biogas owners had the capacity and resources to expand and utilize their knowledge, which benefitted their systems a lot. Excess slurry was often mentioned as a problem among the participants as it was challenging to sell, and many had too much slurry for their use. The slurry has a great potential as a fertilizer, so by not using or selling it, the excess slurry can count as lost profit. Some participants explained the hesitance of using slurry due to social taboo and lack of knowledge. The more resourceful participants were able to expand their systems and utilize the slurry. Others had fewer resources and capacity constraints that prohibited the expansion of their system and knowledge. The critical factors became more visible with their plants compared to the more resourceful participants. The studies on biogas' potential in developing countries (Roopnarain and Adeleke, 2017, Patinvoh and Taherzadeh, 2019, Wassie and Adaramola, 2019, Clemens et al., 2018) often neglect to mention the complexity of the system in which the biogas plant takes part, and that a biogas system is not a fitting solution to everyone with property and cows.

Among the participants in Uganda, the living conditions and standards varied greatly. Some of the participants lived in bigger houses, used some electricity, which is not too usual in the rural areas, and had completed higher education. Those who had more extensive education and were more resourceful showed capacity and ability to acquire knowledge and utilize it in their daily routines. The participants who had more of a struggle to get ends to meet did not seem to have the capacity to learn more about biogas plants and system optimizing. The complexity of a biogas plant and the necessary planning of the system can be challenging to manage for people with other fundamental challenges that need attention.

It is common with free-grazing cows during the daytime in many developing countries, including Uganda. When cow dung is the primary substrate of a biogas plant, the cows will often have to be stabled during the daytime as well, and the feed costs will increase. Additionally, the high installation costs of the biogas plants and the lack of financial mechanisms will affect the less resourceful people to a greater extent than the more resourceful. The high upfront installation costs of biogas plants can be problematic for individual households, but still possible for bigger farms, schools, prisons, or collaborative within a village.

Nyenga Foundation had a large biogas plant with the involvement of several people, which demand a well-structured regime and routines. The start-up phase at the foundation showed the necessity of having one person in charge who had the competence of planning the whole of the biogas system and the daily routines. A biogas plant owned by an organization has a risk of losing the ownership feeling that is an essential factor to sustain routines and the willingness to increase the knowledge. As previously mentioned, the biogas system at the foundation had some impractical solutions that increased the workload for the workers during the analyzed period. It was considered necessary that all relevant employees knew the benefits of the biogas system to sustain the routines. The ones in charge of the plant had to learn a lot about the way it functioned and how to manage it. The most important factor seemed to be the transfer of knowledge and enthusiasm towards the system. When the employees saw the benefits of the biogas plant, it was possible to use their experience to create routines adapted to their workdays.

One of the informants in Uganda said that when something went wrong, like the clogged plant at Nyenga Foundation, an unwillingness to retry became evident. Instead of trying again after failure, the fails stopped all further learning and trying. The studies of technology transfer and biogas implementation state the importance of learning from mistakes and using the knowledge to try again. The statement from the informant in Uganda can suggest a common fear of mistaking and failing. The fear of failing can turn into hesitance of trying and lead to a slow or no development. Policies from the government could overcome the barrier if reducing the risk or consequence of failure. It could be policies that make the upfront costs lower, or campaigns promoting the possibilities of biogas systems.

The studies used on anaerobic digestion says that the most beneficial for the biogas plant and gas production is to combine different substrates in the digester; both animal dung and bio-waste. Still, the informational brochures available for the biogas owners in rural areas of Uganda, and possibly several African countries, are lacking information about the substrate opportunities other than cow dung. In correlation with economic growth, is increasing waste amounts, including bio-waste. This signifies that it is likely to become more bio-waste available with the increasing development of the country. By planning and informing about the possibility of utilizing the organic wastes, waste management will have a system, and gas production can increase. Among the participants in Uganda, none other than Nyenga Foundation used bio-waste in their digester. Grass clippings from the garden and football field were added to increase daily input amount and biogas production. Some of the participants had, at some point, tried using bio-waste but experienced that the pieces came out undissolved in big pieces and were hesitant to try again. Reasons for it not to work could be that the bio-waste was in too big pieces, that it was too hard or dry, or that the HRT in the digester was too short.

Overfeeding of the digester was one of the most common challenges among the participants, and results in a short HRT and low biogas yield.

5.4 Future possibilities for Nyenga Foundation's biogas plant

The inclusion of biogas systems in the educational programs could start at Nyenga Foundation's school. The pupils could over the seven years of primary school learn about the different aspects of a biogas plant and management of systems. Nyenga Foundation has a unique opportunity to include more practical and sustainable learning that could benefit the children.

All of the participants in Uganda had domestic biogas plants with a continuous flow system, which needs to get a daily input of new substrates. It is essential to use gas regularly, preferably daily, to sustain a flow in the biogas plant. At Nyenga Foundation's primary school, there are only students 240 days a year, and this leaves 125 days of possibly unused gas. Nyenga Foundation can let the children's home and the houses inside the foundation use the gas stoves when the school is closed for weekends and holidays. In exchange for gas, they could provide the plant with bio-waste to increase the daily input and expected methane yield. Everyday use of gas creates a flow in the digester and increases the production potential even when the school is closed. Possible bottlenecks are logistic concerns and responsibility for correct usage of equipment.

The excess slurry could become a possible income for Nyenga Foundation or other biogas plants. Information about the slurry's benefits and safety will have to be promoted more in order to see increased demand from people. Although many are starting to use slurry as fertilizer, there is still much doubt about using it on food crops. Nyenga Foundation, with its many connections, could create a hub for sale slurry. It could potentially create awareness of slurry benefits and provide extra income for the foundation. As many of the smaller domestic plants struggled with their overflood of slurry, Nyenga Foundation could collect slurry from them as an additional supply. This would help both the other biogas owners and the foundation itself.

6 Conclusions

This thesis aimed to explore whether domestic biogas plants for cooking purposes can be a viable solution to users in rural Uganda. The economic assessment and the evaluation of critical factors proved that the high upfront installation costs are a significant barrier to the broader implementation of domestic biogas plants. Installation might be more profitable for larger organizations or institutions, as the analyzed plant of Nyenga Foundation, than for individual households. Of the most commonly used cooking alternatives, the results suggest that biogas has the lowest fuel price. However, compared to the traditional woodstoves and electric ovens, domestic biogas plants demand a lot more knowledge from the users, which makes the social factors essential. Education in system operation and training of biogas users are critical factors for continued operation.

The interviews in Uganda showed that a biogas plant is likely to be more viable when the complete system is well planned, and all benefits are taken advantage of, which concerns especially the utilization of slurry. Resourceful people who have capital and competence to sustain operation and increase their knowledge had the most successful biogas systems. The focus for further development of biogas use should emphasize the availability of information on benefits and potential from biogas systems, not just the biogas but the full system. The high installation costs could be addressed by subsidies from the government or by creation of other financial mechanisms adapted to the local situation. This thesis suggests that developing countries' goals for sustainable development with biogas plants should focus on the implementation of viable systems for users, and not a high number of installed plants in the country.

7 Bibliography

ABPP. 2020. *Uganda* [Online]. Available: https://www.africabiogas.org/countries/uganda/ [Accessed 12.02.2020 2020].

CLEMENS, H., BAILIS, R., NYAMBANE, A. & NDUNG'U, V. 2018. Africa Biogas Partnership Program: A review of clean cooking implementation through market development in East Africa. *Energy for Sustainable Development,* 46**,** 23-31.

CORSI, A., PAGANI, R. N., KOVALESKI, J. L. & LUIZ DA SILVA, V. 2020. Technology transfer for sustainable development: Social impacts depicted and some other answers to a few questions. *Journal of Cleaner Production,* 245**,** 118522.

DIGNITED.COM. 2020. *Compare Cooking Gas Prices in Uganda* [Online]. Available: https://dignited.com/pricegator/cooking-gas/ [Accessed 26.04 2020].

GLOBAL PETROL PRICES. 2020. *Uganda Electricity Prices* [Online]. Available: https://www.globalpetrolprices.com/Uganda/electricity_prices/ [Accessed 22.04 2020].

HAGOS, K., ZONG, J. P., LI, D. X., LIU, C. & LU, X. H. 2017. Anaerobic co-digestion process for biogas production: Progress, challenges and perspectives. *Renewable & Sustainable Energy Reviews,* 76**,** 1485-1496.

HIRSCH, T. S. V. & ADARAMOLA, M. S. 2019. Assessing the feasibility of a solar water heating system in rural Uganda. Norwegian University of Life Sciences, Ås.

IRENA 2016. Measuring small-scale biogas capacity and production.

JHIRAD, D. 1990. Power Sector Innovation in Developing Countries: Implementing Multifaceted Solutions. *Annual Review of Energy,* 15**,** 365-398.

KHABIRI, N., RAST, S. & SENIN, A. A. 2012. Identifying Main Influential Elements in Technology Transfer Process: A Conceptual Model. *Procedia - Social and Behavioral Sciences,* 40**,** 417-423.

KOSSMANN, W., PÖNITZ, U., HABERMEHL, S., HOERZ, T., KRÄMER, P., KLINGLER, B., KELLNER, C., WITTUR, T., KLOPOTEK, F. V., KRIEG, A. & EULER, H. 1999. Biogas Digest (Volume II) - Biogas - Application and Product Development.

KRISHNA, S. & WALSHAM, G. 2005. Implementing public information systems in developing countries: Learning from a success story. *Information Technology for Development,* 11**,** 123-140.

KUMAR, S., LUTHRA, S., HALEEM, A., MANGLA, S. & GARG, D. 2015. Identification and evaluation of critical factors to technology transfer using AHP approach. *International Strategic Management Review,* 3.

MANG, H.-P. & LI, Z. 2010. Technology review of biogas sanitation.

NES, W. V., LAM, J., HEEGDE, F. E. W. T. & MARREE, F. 2009. Building viable domestic biogas programmes : success factors in sector development. *In:* NGUYEN, Q., WATTS, H. (ed.). [The Hague].

PATINVOH, R. J. & TAHERZADEH, M. J. 2019. Challenges of biogas implementation in developing countries. *Current Opinion in Environmental Science and Health,* 12**,** 30-37.

ROOPNARAIN, A. & ADELEKE, R. 2017. Current status, hurdles and future prospects of biogas digestion technology in Africa. *Renewable and Sustainable Energy Reviews,* 67**,** 1162-1179.

SURENDRA, K. C., TAKARA, D., HASHIMOTO, A. G. & KHANAL, S. K. 2014. Biogas as a sustainable energy source for developing countries: Opportunities and challenges. *Renewable and Sustainable Energy Reviews,* 31**,** 846-859.

TABATABAEI, M. & GHANAVATI, H. (eds.) 2018. *Biogas: Fundamentals, Process, and Operation*: Springer.

THE NATIONAL PLANNING AUTHORITY 2013. Uganda Vision 2040.

TRADING ECONOMICS. 2020. *Uganda Interest Rate* [Online]. Available: https://tradingeconomics.com/uganda/interest-rate [Accessed 08.04 2020].

UNITED NATIONS 2013. Third synthesis report on technology needs identified by Parties not included in Annex I to the Convention.

WASSIE, Y. T. & ADARAMOLA, M. S. 2019. Potential environmental impacts of small-scale renewable energy technologies in East Africa: A systematic review of the evidence. *Renewable & Sustainable Energy Reviews,* 111**,** 377-391.

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway