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Perspectives and Challenges of Biogas Technology in Zambia, Evidence from Western Zambia

Master's Thesis

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Declaration

I hereby declare that this thesis entitled “Perspectives and challenges of biogas technology in Zambia, evidence from Western Zambia” is my own work and all the resources have been quoted and acknowledged by means of complete references and according to citation rules of the FTA.

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Prague, 6th August 2021

Ernest Kwabena Allotey

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Abstract

An important technology which aids environmental improvement through organic waste management and at the same instance produces both biogas for energy utilization and fertilizer for enhancing agricultural productivity is the anaerobic digestion process (AD). In many developing countries, the spread of the use of biogas plants is evident and hence the associated technical and operational challenges with their use are increasing. This study, therefore, puts into perspective the challenges (technical and operational) with the technology at the level of small-holder biogas plant users (n = 20) in the western province of Zambia. In March - May 2020, a field survey was conducted on biogas plant users in western province of Zambia. Data collection methods employed in the survey included personal interviews based on a structured questionnaire. The findings revealed that on the average the farmers own 30 cattle per household which assures enough cattle manure to supply feedstock for biogas production. Computations show that Zambia has a theoretical biogas potential of 57,874 $TJyr^{-1}$ from animal dung, which is more than sufficient to supply the energy needs of the country. The concept of problem analysis was employed to identify and analyze the different challenges encountered by the biogas plants (BGP) users in the study. Per the survey, 75% of the population of biogas plants (BGPs) users in the western province of Zambia have encountered some challenge with the technology; the most frequent is leakage in reactor which can impede the proper functioning of the BGPs. Other challenges identified by the respondents include but not limited to malfunction of biogas cookers, breakdown of AD process, leakage of feedstock (oversized BGPs), solid digestate floating in tanks and several other challenges as discussed in the text. BGPs users in western province of Zambia therefore, request for properly trained and dedicated builders (masons) with the technical know-how to solve problems encountered with BGPs with swift.

Key words: Anaerobic digestion, organic waste, animal dung, small-scale biogas plants, technical and operational challenges, problem analysis

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List of the abbreviation used in the thesis

AD	Anaerobic Digestion
BGPs	Biogas Plants
CDM	Clean Development Mechanism
CDVM	Categorical Dependent Variable Model
FAO	Food and Agricultural Organization
FAOSTATS	Food and Agricultural Organization Statistics
FNDP	Fifth National Development Plan
GHG	Green-House Gas
OLS	Ordinary Least Square
OM	Organic Matter
PA	Problem analysis
PIN	People in Need
REFIT	Renewable Energy Feed in Tariff
RETs	Renewable Energy Technologies
SDGs	Sustainable Development Goals
SIDA	Swedish International Development Agency

SNDP	Sixth National Development Plan
SNV	Netherlands multinational organization
SSA	Sub-Saharan Africa
UN	United Nations
WPI	Western Province of Zambia Information

1. Introduction

Energy plays an essential role in every society. It serves as one of the fundamental inputs that ascertain the status and pace of development of every nation. As part of the aims of the United Nations Sustainable Development Goals (SDGs), there is the need to provide affordable, reliable, and sustainable energy to all. Zambia, a southern African country is known for its abundance of renewable and non-renewable energy resources. Such energy resources include vast water reserves, industrial minerals such as coal, agricultural land, abundant forest, abundant wind, and intensified annual sunlight. Thus, rural households in Zambia traditionally use biomass (firewood, charcoal, dung, and agricultural remains) for cooking and water heating purposes which has negative impact on the environment through deforestation, requires high demand for labour force and time for collection of the biomass, and presents a high health risk via the burning of the biomass to its users. Therefore, there is need for a more sustainable source of energy and hence utilizing livestock manure to produce biogas appears appropriate to supply enough energy at the household level. This approach could contribute to organic waste management practices that can protect the environment and at the same time produce organic fertilizer (bio-slurry) for small-scale farmers to enhance their production efficiencies.

The renewable energy sector of developing countries, however, continues to face several critical challenges regarding the development and supply of sustainable renewable energy sources, which can be explained by several factors (Linjordet et al. 2020). Among the major factors limiting energy progress in developing countries is energy shortage. Hence, accessing appropriate energy by the local population while keeping a clean environment, good health conditions and progressing economically is a challenge. Due to this shortage in energy, global attention has been drawn to renewable energy production as an alternative source of energy (Mushtag et al. 2016). Rural energy poverty among populations of developing countries contributes to limitations in the improvement in their sustainable livelihoods (Li et al. 2016). Therefore, sustainable supply of adequate, affordable, efficient, and reliable energy sources has become relevant to solve the world's energy crises (Chang et al. 2014). To achieve this, the development of renewable energy is crucial in solving the world's energy problems (Barasa et al. 2018).

Further, increase in population, industrialization, and urbanization in developing countries have posed several challenges through increased waste production (Dhokhikah and Trihadingrum 2012). Therefore, the need to improve waste management practices in highly populated countries can lead to the development of alternative affordable and clean energy resources. This has the potential of contributing to poverty alleviation and human development as has been the priority of many international organizations focusing on the search for appropriate energy (Martí-Herrero et al. 2015). To achieve this, an appropriate technology to use is small scale biogas plants that can convert organic waste materials into bioenergy (biogas) and organic fertilizer (Roubík et al. 2016).

2. Literature Review

This chapter is focused on reviewing the literature relevant to biogas technology and its importance in addressing the world's energy problems. Several studies have been conducted on biogas technology and hence have a bearing on this research. The chapter, however, reviews these studies to lay that establishes the context within which the study can be comprehended. The theoretical framework employed in the analysis of the study is formulated via the literature reviewed.

2.1 Africa's Biogas Technology Industry and its Status

Biogas technology is one of the renewable energy technologies that aids the alleviation of Africa's energy and environmental challenges. Africa's interest in biogas technology in current times have been stimulated by the efforts of many international organizations and foreign aid agencies amid research publications, visits, and meetings (Nethengwe et al. 2018). Several countries within sub-Saharan Africa have mounted biogas digesters which use different types of waste from industrial waste, slaughterhouses, animal dung, municipal waste, as well as crop residues.

All over Africa, especially among Sub-Saharan Africa (SSA), several small-scale biogas plants have been mounted but only a few of them are operational. Most of these countries produce biogas through anaerobic digestion of animal excreta by utilizing either the Chinese fixed-dome biogas digester or the Indian floating-over biogas digester (Omer & Fadalla 2003). Among the beneficiaries of these built digesters are schools, health sectors, and small-scale farmers, which in most cases are sponsored by non-governmental organizations (Mfune & Boon 2008). A higher proportion of these biogas plants mounted and installed in Africa have functioned shortly due to technical challenges and poor maintenance culture of some SSA countries (Patinvoh & Taherzadeh 2019). Therefore, there is the need to develop Africa's biogas sector by introducing more efficient reactors that would enhance biogas yields and improve the existence of the technology. Small-scale anaerobic biogas production in SSA remains at the infant stages even though the continent has a lot of potentials (Simwambi et al. 2020).

Sub-Saharan Africa has a considerable amount of renewable energy resources, however, only a small proportion of these resources have been exploited (Mwirigi et al. 2014). The energy sector development in the eastern and southern African countries have been achieved by contributions from renewable energy technologies (RETs) acquired through limited initiatives that have been embarked on till date. Rural energy demand has been provided by RETs by utilizing locally available resources and expertise and hence provides job opportunities for the local inhabitants (Karekezi & Kithyoma 2003). Energy, sanitation, and hygiene interventions mostly regarding low-income households often attract attention to support multiple development goals in a more effective and integrated approach. Most low-income households in SSA lack the basic facilities including cooking facilities, rudimentary places of convenience and as such are involved in various unhygienic practices. To meet the daily cooking needs of most African households (about 80 to 90 percent) traditional biomass fuel including firewood, charcoal, dung, and agricultural remains are their main sources of energy (Lim and Biswas 2019).

It is therefore appropriate that contemporary energy technologies and sources of energy with less environmental impacts coupled with sustainability compared to traditional sources of energy are invested into by SSA nations (Parawira 2004). Hence, anaerobic digestion (AD) with energy recovery in the form of biogas is an attractive method for the treatment of solid waste and liquid waste. This process consists of many complex interdependent, sequential, and parallel biological reactions devoid of oxygen, in which products from a group of micro-organisms become the substrate for the subsequent group, leading to the formation of a mixture of methane and carbon dioxide from the transformed organic matter (Noykova et al. 2002). Apart from biogas derived from AD, other benefits include reduced volumes of waste, biofertilizer production and essential soil conditioners especially from large volumes of municipal, industrial, and agricultural solid wastes (Lettinga 2004; Grommen and Verstraete 2002). Waste of all types and volumes can be treated through AD process (Zeeman and Saunders 2001). The production of biogas from agricultural residues, industrial and municipal wastes does not compete with the production of food crops in terms of land, water and fertilizers as compared to the production of bioethanol and biodiesel (de Baere 2000).

Developing countries are facing a lot of food crisis currently (Surroop et al. 2019), which is not ending soon. Therefore, more emphasis should be placed on producing more food than the production of energy crops for bioethanol and biofuel production. Through biogas technology, environmental pollution is controlled, and nutrients are recycled to reduce the over-dependence on imported fossil fuel (Kemausuor et al. 2018). Similarly, biogas technology aids in the reduction of forest resources used for household energy purposes and hence reduce deforestation and its emanating challenges (Uhunamure et al. 2019). Relative to other forms of renewable energy, biogas production technology is simple and can be operated both in the urban and rural settings on small and large scales (Clement et al. 2018). The utilization of biogas technology has no limitation, and it is not confined to a location; that is, it is not monopolistic to a location (Jafari-Sejahrood et al. 2019). Electricity and heat can be produced from the anaerobic digestion of large volumes of municipal, industrial, and agricultural solid wastes and the residues (bio slurry) from the digester can be utilized as a secondary fertilizer for agricultural purposes (Iocoli et al. 2019). In America, China, and Europe, anaerobic digestion has been introduced on a full scale where it has been discovered that municipal, industrial, and agricultural solid waste are essential sources of renewable energy and plant nutrients (Weiland 2000; Mata-Alvarez et al. 2000).

Under the Clean Development Mechanism (CDM), that is, one of the flexible subsidiaries specified in the Kyoto Protocol, a successful biogas implementation project has a high affinity for funding on the condition that it can reduce greenhouse gas (GHG) emissions and can substitute fossil fuels and inorganic fertilizers (Baird and Green 2020). Essentially, biogas produces clean and efficient sources of energy, helps to eradicate, or reduce health issues associated with the consumption of biomass traditionally and in addition helps to boost employability of individuals through its production (Walekhwa et al. 2009). Access to clean and modern energy is an important focus of the SDG7, including the other specific SDGs on good health and well-being, gender equality, climate action and poverty eradication. Despite the health risks associated with the use of traditional biomass, Welfle et al. (2020) reports that more than 2.5 billion people of the world's population are dependent on it for their energy needs.

Further, SSA has a high biogas potential and abundant of feedstock to produce this renewable energy, which has the potential to curtail the continent's energy and environmental challenges (Parawira 2009). However, a large proportion of domestic biogas digesters installed in SSA till date are not functioning (Amigun et al. 2012). Based on this study background, Zambia's renewable energy sector is put into perspective and biogas is specifically chosen because it has the potential to eradicate poverty through sustainable energy interventions.

2.2 Biogas Production and Commercialization Challenges and Possible Ways to Overcome Them

According to Omer & Fadalla (2003), large scale implementation of biogas technology faces several political, social-cultural, financial, informational, institutional, technical, and training challenges. Specifically, some of the challenges encountered in the implementation and development of biogas technology in most developing countries can be listed as mentioned by Patinvoh and Taherzadeh (2019) below:

1. 'Poor choice of materials used in the construction of biogas plants due to inexperienced contractors and consultants.'
2. 'Lack of reliable information on biogas potential benefits to stakeholders, especially financial institutions.'
3. 'Absence of infrastructural development towards academic, bureaucratic, legislative, and commercial biogas achievements in the region.'
4. 'Inadequate knowledge on the technology in focus, even on the part of research institutions and universities.'
5. 'Poor maintenance and repairs of biogas plants by owners.'
6. 'Lack of pilot studies and full-scale research experience in biogas technology in most developing countries.'
7. 'Biogas operators in the region lack the skills, credibility, and technical knowledge on the technology.'
8. 'Authorities and policy makers are partially informed on biogas technology.'
9. 'Lack of governmental support on biogas technology through national energy policy.'

More importantly, problems facing the production and commercialization of biogas technology in SSA countries are generally influenced by economic and site-specific factors.

Amingu and von Blottnitz (2007) explained the economy of a biogas plant to consist of large investment costs, operations and maintenance costs, raw materials (feedstock) which mostly are free such as animal dung, water, sewage sludge, industrial waste, agricultural residues, and income gains from the sale of biogas. The production and consumption of biogas depends on several economic factors specific to the location (country) and project situation of the BGP. Such factors of the economy which affect the production and commercialization of biogas include,

1. Cost of biogas materials, which is relative among countries and depends on the availability of land, agricultural productivity, cost of labour including many others.
2. Costs of biogas production, which is determined by the BGP location, size of plant, varying among countries.
3. Corresponding fossil fuel (gasoline, diesel) costs specific to each country.
4. Benefits which are strategic resulting from substituting imported petroleum with domestic energy sources.

The development of renewable energy in SSA is an incremental process and not a hasty process. It therefore depends on households, national and regional technological capacities to make the transition a successful one (Murphy 2001).

Most rural households in SSA are not able to afford the investment costs of even the smallest of the biogas units, hence there is the need for demand-driven and market-oriented subsidy-led programmes that would increase the adoption of biogas technology. In addition, this is necessary to make up for the difference between the rural people's ability to pay and the households and societal benefits such as reduction in expenditure for firewood and kerosene, time savings for cooking and firewood collection, forest cover maintenance, land degradation prevention and reduction in greenhouse gas emissions (Mshandete & Parawira 2009). Furthermore, besides the costs, many households are hesitant to adopt biogas technology because of the lack of public awareness of the relevance of the technology (Patinvoh and Taherzadeh 2019).

The site-specific factors that limit the production and commercialization of biogas in SSA include but not limited to water availability and organic materials (feedstocks) for the effective operation of biodigesters. Limitations in water availability poses a major challenge to biogas operations in some countries because biogas plants (BGPs) typically require a mixture of water and manure substrates in equal proportions to effectively operate. Small-scale farmers in most developing countries lack sufficient domestic animals, hence they are not able to obtain the required amount of manure substrate for the operations of biodigesters to produce sufficient gas for cooking and lighting. Even where enough animals are available in households, the extensive system of keeping the animals (semi-nomadic or free-range system) does not make it easy to collect the dung to feed the digesters (Abbey 2005). The community type of BGP might be more feasible in clustered communities in countries like Ghana, Nigeria, and Zambia (Akinbami et al. 2001).

Often, the introduction of energy technology projects in developing countries are embarked without proper assessment of the needs, problems, capabilities, and priorities of the beneficiaries of the project. Hence there is the need to take motivation from past projects. The biogas water pumping project in Botswana in the mid-1980s is a typical example of how mis-assessment of the target beneficiaries' needs, and problems resulted in project failure (Parawira 2009). In this project, the aim was to introduce biogas as the main pumping fuel for water in some communities in Botswana. The dry climate of Botswana prompted the government of the period to embark on such project as water supply is a priority in the country. The project's failure was due to socio-economic challenges and not technical challenges. This is because, targeted communities who benefitted from the biogas-pumped water project felt disadvantaged when they had to pay for the collection of water with cattle dung operated pumps, whereas their counterparts in other communities enjoyed at no cost government or donor supplied diesel-operated engines. The focus of Botswana's government was rather on biogas to reduce dependence on imported diesel which was different from the perceptions of the project's beneficiaries. Today the BGP installed under the project are not in use. This explains why it is necessary to fully assess and understand individual's interest and perceptions of a project before implementation.

Furthermore, one important obstacle to the penetration of biogas technology projects onto the SSA market is the lack of coordination among institutions and conflicting interests of targeted groups (Davidson 1992). Renewable energy projects implemented without proper consultation with the intended recipients and beneficiaries are likely to face acceptance challenges and premature termination of project. This situation can be resolved when the formulation, implementation and rationalization of institutions are done around the intended groups.

2.3 Energy Policy in Zambia

The national energy policy in Zambia recognizes renewable energy promotion, particularly biofuels, as well as biogas but places more emphasis on energy from hydroelectricity in the country (Shane et al. 2015). In this light, the energy regulation was amended to include energy from biofuels as it was initially excluded from the policy. Similarly, the fifth national development plan (FNDP) of the country places more emphasis on hydroelectric energy relative to that of renewable energy. Even though the plan speaks of promoting biofuels development and biomass, yet it does not specify strategies on how to achieve this plan (Mfune and Boon 2008). Further, unlike the FNDP, the sixth national development plan (SNDP) has among its strategies, explicit biogas promotion for cooking, lighting, and heating, but lacks the exact strategy to achieve it.

The Zambian government in 2008 drafted a national energy policy framework which sought to diversify the country's energy mix by incorporating the use of renewable energy technologies (SREP-Ministry of Energy 2018). To be able to achieve a successful implementation of this policy, the government incorporated private sector investment and encouraged the conditions that are in accordance with the national development goals which ensure the availability of adequate supply of energy from different sources. Furthermore, the formulation of the Renewable Energy Feed in Tariff (REFIT) strategy was implemented to harness the potentials of the renewable energy sector. The aim of this strategy was to enhance economic growth and improve the people's welfare through the implementation of small and medium-sized renewable energy technology projects in rural and peri-urban settlements.

2.4 Zambia's Energy Situation

Zambia's energy situation is typical of most countries within the SSA, but distinguishable based on the country's extreme high production levels of renewable energy (Sovacool 2012). Zambia has approximately 6000 megawatts (MW) of unused hydropower potential of which only 2803 MW is installed and utilized (Kruger & Eberhard 2018). This is because of the country's possession of large water resources located at the Southern zone. Despite Zambia's endowment in both renewable and non-renewable energy resources, the country's energy sector has seen little improvement in industrial expansion, job creation as well as poverty reduction (Adedoyin et al. 2021). The country's energy market is dominated by traditional wood fuels (biomass), typically of firewood and charcoal derived from natural woodlands and agricultural lands. Energy consumption by Zambian households constitute about 70% of energy from biomass sources, that is from charcoal, firewood (Jürisoo et al. 2019). Due to the cheaper cost of this source of energy, deforestation is on the increase in the country (Nansikombi et al. 2020). Currently, Zambia's total energy demand exceeds the nation's internal energy generation capacity. This situation can be explained by expansions in the country's mining sector, manufacturing (industrial) sector as well as the total expansions in the economy and population (Ngoma et al. 2018). Zambia continues to face prolonged load shedding and power cuts which has negative effects on trade and production resulting from the country's current power deficit situation.

Across the rural and urban settings in Zambia, the main lighting sources are candles, grid-based electricity, paraffin, and solar power, representing 27.7%, 22%, 20.3% and 2.9% of households in the country, respectively (Moonga & Chileshe 2019). In addition, the main source of energy employed in cooking throughout Zambia is wood fuel, which is used by more than 50% of the households, followed by charcoal and electricity usage at 30% and 17% respectively. However, the use of charcoal in the urban settings of Zambia dominates with about 54% of the households utilizing it as their main fuel, followed by electricity (about 40%) and wood fuel (about 7%) (Jürisoo et al. 2019).

The use of charcoal (locally called *malaka*) has since the 1930s dominated as the main energy source for urban cooking and hence, minimized the use of wood fuel in Zambia. Further, the 1970s saw several other agencies including universities, government authorities and NGOs carried out experiments with various alternatives to help minimize charcoal use in Zambia. However, the 21st century has presented the country with several environmentally minded social entrepreneurs carrying out various experiments and introducing efficient biomass pellet cookstoves in Lusaka, Mongu, Kalabo and other several settlements in Zambia (Peša 2017). Proper use and development of the country's energy resources can lead to competitiveness in the industry, rural service delivery enhancement and reduction in rural poverty through job creation. It is therefore in the country's vision on energy to 'achieve a universal access to clean, reliable, and affordable energy at the lowest total economic, financial, social, and environmental costs.' Zambia's energy goal is therefore, to increase renewable energy sources and reduce share of wood fuel use to about 40 percent (SREP-Ministry of Energy 2018).

2.5 Biogas Technology Development Interventions in Zambia

In developing countries, the Netherlands multinational organization - SNV has contributed to domestic biogas programs with the sole aim of establishing commercially viable technology in which the marketing and installation of biogas plants for households are undertaking by local companies. Developing countries that benefitted from this intervention include Vietnam, Bangladesh, Cambodia, Indonesia, Senegal, Burkina Faso, Ethiopia, Tanzania, Kenya, and Cameroon where more than 475,000 domestic biogas plants were mounted in the year 2012 (World Bioenergy Association, 2020). However, due to the lack of fiscal policy and strategy to implement modern energy technologies, the efforts of SNV were not fully realized (Zhang et al, 2014).

In Zambia, domestic bio-digesters locally known as Zam-Digester were installed by SNV and SIDA which served as supplements to sources of conventional fuels in the country (World Bioenergy Association, 2020). The People in Need (PIN) biogas project in Zambia from the year 2018 to 2020 also supported the construction of domestic biogas plants (about 10 biodigesters) with the aim of supplying local farmers gas needed for cooking and in addition provides them with new skills and knowledge on how to eco-efficiently utilize the manure from their livestock(as organic fertilizer). Over the decades, biogas projects within the country have proven unsuccessful and hence the likelihood for such projects to be successful in the country will depend on solving the adoption, implementation and operational challenges persisting in the sector. Below is the image of a typical type of biodigesters constructed under the PIN biogas project in Zambia.

Source: People in Need Report (2018)

Figure 1. A Typical Biodigester Constructed Under the People in Need Project in Zambia

2.6 Statement of the Problem

Zambia possesses a high production potential of biogas in rural areas where rearing of cattle and other livestock exist (Clemens et al. 2018). Considering the abundance of feedstock and financial resources in the country, rural inhabitants could cooperate and install biogas digesters. In Zambia, about 18 domestic biogas digesters with capacities ranging from 4 to 26 m^3 were installed by the National Institute for Scientific and Industrial Research between the period 1982 to 2004. These installations were donor funded but are currently not functional (Kasali 2008). The Water and Sanitation Council of Zambia in collaboration with its co-operating partners have since 2008 to present day mounted and installed about 60 domestic biogas digesters of various sizes from 4 to 80 m^3 with financial support from donors, private companies, and clients base (Graefnitz et al. 2013). However, Zambia has been unsuccessful with biogas production projects and therefore, there is a propensity that the country will be unsuccessful even with the revived efforts within the biogas sector, unless the challenges regarding the implementation of the technology are resolved. Secondly, despite the numerous values and benefits of biogas technology to humanity, it is interesting that the technology has not been given much attention by majority of the rural households in Western Province of Zambia. Considering the afore-stated backgrounds, the study evaluated biogas technology potential within the study area, reviewed the status of biogas production, identified challenges (technical and operational challenges) to implementation of biogas production and finally made some recommendations.

3. Research Aims

The main objective of the study is to estimate the potential of biogas technology utilization in the Mongu rural settlement in the Western Province of Zambia.

Specifically, the specific objectives of the study are:

i. From a broader perspective, to estimate the theoretical potential of biogas from animal dung in Zambia;
ii. To describe the socio-economic characteristics of respondents (biogas plant users) in the PIN biogas project in Western Zambia;
iii. To evaluate the respondents' satisfaction (training, use and overall) in Western Province of Zambia;
iv. To identify the technical and operational challenges influencing biogas technology implementation in Western Province of Zambia.

3.1 Hypothesis of Study

It was analysed if there exist any dependencies among the variables which could influence the respondents' participation in the PIN biogas project in Zambia. The variables considered in the analysis included: gender, age, achieved education, size of farmlands, age of BGP, daily operation of the BGP and share of income contributed from agricultural activities at 5% level of significance.

The hypothesis formulated whether the respondents' amount they are willing to spend on BGP repairs was influenced by the share of income contributed from agricultural activities was:

H_0: There is independence of the respondents' amount they are willing to spend on BGP repairs and their share of income from agricultural activities.

H_1: There is significant dependence of the respondents' amount they are willing to spend on BGP repairs and their share of income from agricultural activities.

3.2 Problem analysis conceptual framework

The study adopts a problem analysis (PA) method from Roubik et al. (2016), which identifies, describes, and suggests possible solutions and recommendations to potential challenges encountered by BGPs users in western province of Zambia. The application of this approach in the study is justified by its potential to categorize and describe the possible technical and operational challenges in the study area into the six main subsystems of biogas plants and provides space for possible solutions and recommendations to be made. This approach has been used in several studies including Afridi and Qammar (2020), Roubik et al. (2016), Sammer (2010) and many others. This study intents to enhance the adoption or use of biogas technology, improve, and prevent possible technology failures in the future. To achieve these, the PA method links the main technical and operational challenges encountered by small scale BGPs users in the study area to the six main biogas plant subsystems as used by Roubik et al. (2016); namely:

1. Structural components
2. Piping systems
3. Equipment utilizing biogas.
4. Digestate disposal systems
5. Anaerobic digestions processes and biogas utilization
6. Knowledge-related challenges

Challenges encountered in these subsystems are identified through the administration of questionnaires and then described and recommendations are made based on information from several studies in the discipline. The entire small-scale biogas system functions properly when these subsystems are addressed in tandem. According to Roubik et al. (2016), a failure in a biogas system is usually because of a failure in one or more of these subsystems mentioned above.

4. Methodology

The study estimated the theoretical biogas potential of Zambia from animal dung using statistical data on livestock production from Food and Agricultural Organization (FAO) of the United Nations (UN) database. The study also conducted a baseline field survey among participants of the PIN biogas project in the Western Province of Zambia. The study sourced factual background information from the respondents on their satisfaction levels as well as challenges they encounter in the operation of BGP.

4.1 Study Area

The study was conducted within the Mongu district in the Western Province of Zambia, which is one of the provinces subjected to the support within the interventions focused on agricultural and health sector funded by the Development Cooperation of the Czech Republic (Lenormand and Rovny 2020). Among the administrative provinces in Zambia, the Western Province is the largest with a total land area of 126,386 km^2 (WPI 2017). The province is bounded by the Central Province in the East, North-western Province in the North and the Southern Province in the South-eastern part of the country. The Western Province is made of 16 districts, with Mongu district as the capital of the province. The 2010 population census established the total population of the province to be 881,524 inhabitants (WPI 2017).

The economy of Zambia in recent past has been experiencing negative growth rate and has remained under controlled at 3.8% because of the poor performances in many sectors of the country's economy ((SREP-Ministry of Energy 2018). The country's poverty and inequality rates as compared to other countries in SSA is very high. The Western Province of Zambia is among the regions where the need to reduce poverty resulting from the lack of access to alternative sources of energy face challenges, especially within the peri-urban settlements. Mongu district is the focused study area in this project as it is among the districts regarded as having high energy poverty population.

The Mongu district was chosen as the location for this study because it is among the districts with peri-urban community setups where renewable energy projects for poverty reduction was introduced and implemented by some international development organizations including Heifer International, SNV – Netherlands, People in Need (PIN) and Swedish International Development Agency (SIDA) (Ghimire 2013). In addition, the households within the Mongu district are mostly small-scale livestock farmers with the potential of supplying the required (needed to power the biogas plant) feedstock (cattle dung) to the domestic biogas digesters constructed under the various renewable energy projects (Sanches-Pereira et al. 2015).

Figure 2. Map of Study Area

4.2 Target Group and Sample Size

The survey targeted beneficiaries of the PIN biogas project in Western Province of Zambia as these are the only owners of BGPs currently being in operation. We have detected another biogas plant which exists in Limulunga but is not operating anymore. In addition, we were not able to reach the owner for an interview. Out of the 24 beneficiaries (BGP owners) in the PIN biogas project in Western Province of Zambia, who are the total population of the owners having their BGPs in operation, we managed to interview 20 of them due to severe restrictions on COVID – 19 pandemic out-break. Some respondents were visited personally, some were interviewed only via phone call. The original research design included twice big control group selected from the same communities as the BGP owners; however, due to the lockdown and mobility restrictions we were unable to manage such data collection segment.

4.3 Data Collection

The study was based on two data sources, namely primary and secondary data. The secondary data was sourced from the Food and Agricultural Organization Statistics (FAOSTATS) database (2018) for the estimation of Zambia's biogas potential from livestock. The primary data component was sourced from beneficiaries of PIN biogas project in Zambia since the project's commencement in the year 2018. Data collection was on the socio-economic characteristics of respondents as well as sections related to biogas technology. The data was collected in the year 2020 during the COVID-19 pandemic period in Zambia. The method of data collection employed in the study included personal interviews based on a structured questionnaire, which took approximately 1 hour. The interview was done in a local language – Lozi, but the respondents were reported directly in English. Two local experienced and trained enumerators (female and male) were employed for the data collection. The questionnaire was designed to reveal the satisfaction of the beneficiaries as well as the current situation (benefits and challenges) of biogas technology perceived by the users. The composition of the questionnaire included open, closed, semi-open, and multiple-choice questions.

4.4 Methods of Data Analysis

The data collected were categorized, coded, and analysed using the statistical package, IBM SPSS Statistics 27. The nature of the data collected prompted the use of Pearson's correlation matrix (R), to detect possible relationships between respondents' characteristics which influence their satisfaction with BGPs under the PIN biogas project. In addition to the primary data collected (specific information taken from the questionnaire), secondary data (general information related to Zambia as a whole) were analysed from several studies on the perspectives and challenges of biogas technology.

Objective one, which is focused on estimating the theoretical biogas energy potential from animal dung in Zambia is determined by computing equation (2) considering methane composition (Khan et al. 2014, Maghanaki et al. 2013) and the caloric value (Bond and Templeton 2011) of biogas to be between 50 to 70 percent and 23 MJm^{-3} respectively:

$$BP = \frac{N*VS*B_0*365*1.67*23}{10^6} \; (TJ/Yr) \qquad (2)$$

Where:

BP = theoretical biogas potential ($TJYr^{-1}$)

N = population of each animal category (heads)

VS = volatile solids of excrements ($kgh^{-1}d^{-1}$)

B_O = methane potential (m^3kg^{-1})

D = one year (365 days)

C_v = caloric value of biogas at 60% methane (MJm^{-3}) = 23

Objective two was achieved via the adoption of simple descriptive statistics such as mean to describe the socio-economic characteristics of the respondents. Also, Mann-Whitney U test was employed to test the significance in difference among the socio-economic characteristics of the respondents. A non-parametric test was employed because the test of normality based on Shapiro-Wilk and Kolmogorov assumptions (for dataset less than 200 elements) showed that the significance in difference among the socio-economic characteristics deviates from normal.

For dependency detection (correlations) among the various characteristics describing the respondents in the survey, data were analysed with suitable methods adopted from Hanmer & Kalkan (2013) and Omotesho (2014). The categorical dependent variable model (CDVM), which is more accurate compared to ordinary least square method (OLS) was employed for the dependency detections among the respondents' characteristics. The independent variables set for the CDVM include gender of respondents, education levels of respondents, share of income from agricultural activities, maximum amount respondents are willing to spend on BGP repairs, contacts with extension agents, total farm area of respondents under cultivation, respondents' experience with BGP and the total number of cattle owned by the respondents.

Objective three, which is focused on evaluating the respondents' satisfaction levels concerning biogas technology training, use and overall satisfaction under the PIN biogas project in Zambia was achieved by using the method of weighted scores employed for a 5-point Likert ordinal scale (Akila and Chander 2011). Following the procedure by Chimi and Russell (2009), the statement choices were assigned codes (weightings) to be able to quantify the responses as follows in table 1:

Table 1. Weightings to the Statement Choices of Satisfaction Level

Type of statement	1	2	3	4	5
Biogas for cooking	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
BGP operation requirement	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
Economic benefits (biogas)	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
Time saving	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied

The following mathematical equation (1), is then employed for computing the weighted score (WS*) for each of the statement choices based on Chimi and Russell (2009):

$$x = \frac{\sum_{i=1}^{n}(x_i * w_i)}{\sum_{i=1}^{n} w_i} \qquad (1)$$

Where:

Σ = the sum of weightings (summation of the product of the assigned codes and number of responses to each of the satisfaction levels)

w = the weights (codes assigned to each of the responses on a five-point Likert scale)

x = the value (number of responses to each of the satisfaction levels)

Objective four, which is to identify the technical and operational challenges influencing biogas technology implementation in Zambia is carried out by assembling and describing the problems recognized during the field survey and other information from various studies. Challenges identified from our field survey are grouped into each of the subsystems and then the average individual frequencies are computed.This will aid in revealing the current situation of biogas technology implementation in Zambia.

4.5 Limitations of the Study

Some limitations were encountered while conducting this research. Firstly, the accuracy of the data collected on the respondents could not be 100%; as respondents did not have written down records of their activities with the operations of the biogas plants. Hence, the reliability of the data is not assured. Secondly, the emergence of the COVID – 19 pandemic restricted mobility and this had a significant effect on our data collection as some respondents were not reached to be interviewed and hence causing limitations in our data collection. In addition, the original design of our research, which included a control group twice the number of the biogas plant owners in the target area was changed as the pandemic reached its heights. Finally, the population of biogas plant owners used in the study is small and this can affect the results of the study.

5. Results

This chapter explicitly presents the results obtained from our research. This research determined from a broader perspective the theoretical potential of biogas from animal dung in Zambia using secondary data from FAO 2018 database. The study further described the socio-economic characteristics of respondents within the study domain and evaluated their satisfaction levels regarding biogas technology. Finally, the study identified among the respondents technical and operational challenges confronting them on the use of biogas plants.

5.1 Theoretical Biogas Potential from Animal Dung

Computing equation (2) and considering methane composition (Khan et al. 2014, Maghanaki et al. 2013) and the caloric value (Bond and Templeton 2011) of biogas to be between 50 to 70 percent and 23 MJm^{-3} respectively, a theoretical biogas potential of 57,874 TJ per year was estimated from animal dung in Zambia as represented in table 2.

Table 2. Theoretical Potential of Biogas in Zambia

Animal Name	Population (Million)	VS ($kgh^{-1}d^{-1}$)	B_O (m^3kg^{-1})	BP ($TJyr^{-1}$)
Cattle	3.6839	3.0264	0.2267	35,43
Goats	2.8869	0.4054	0.4799	7,874
Pigs	1.2073	0.9825	0.5162	8,584
Sheep	0.2662	0.3472	0.3588	465
Chicken	41.8800	0.0229	0.4103	5,517
Total				**57,874**

Source: Estimations are based on data from FAO 2018 database.

5.2 Socio-economic Characteristics of Respondents

The respondents were male dominated, consisting of 90% males and 20% females as males mostly oversee these installed BGPs. Among the respondents, 55% of them were actively involved in agricultural activities, cultivating averagely more than 4 ha of farmland (Table 3). On the average, the respondents were 51.9 years old with 12 years of formal education, that is secondary education level. The levels of education of the respondents were cited as follows: primary education at 15%, secondary education at 60% and higher education at 25%.

Most of the respondents obtained their incomes from agricultural activities where livestock (specifically cattle) are kept, and crops (including maize, vegetables, and tubers) are grown. The proportion of income among the respondents that comes from agricultural activities ranges from 0% (minimum) to 100% (maximum) with an average share of 55.75% per month (Table 2). Five (5) of the respondents, representing 25% of the total project respondents have 100% share of their income coming from agricultural activities, four (4) of the respondents representing 20% also have 50% share of their income coming from agriculture, three (3) of the respondents representing 15% have 60% share of their monthly income coming from agricultural activities. The other categories were represented by lesser numbers of respondents as 10% and 5% of the respondents have 25%, 80%, 40%, 35% and 30% of their monthly income coming from agricultural activities, respectively. Moreover, 45.0% of the respondents participated in some off-farm activities such as running a shop or store, trading in cattle, as nurses and as teachers. On the average, the project respondents have a large labour force of about 10 workers per farmland and this could be explained by the intensive labour requirements of biogas technology operated farms which involve strenuous activities including the collection of manure (feedstock), water and many other activities for the proper construction and functioning of the BGP.

Furthermore, the forms of energy used by the respondents in the study area include firewood, charcoal, electricity, and biogas. Among these forms of energy utilized by these respondents, the most preferred form of energy as represented by 100% of the respondents is charcoal, followed by firewood with a representation of 75% of the respondents, biogas was third as cited by 45% of the respondents and electricity usage was represented by 10% of the respondents. From these findings, it can be deduced that charcoal and firewood are popular forms of energy used by households within the Western Province of Zambia.

Table 3. Descriptive Statistics of Biogas Users in Western Province of Zambia (n = 20)

	Mean	SD	Min.	Max.
Age of participants (Years)	51.9	8.2	32.0	72.0
Formal education of respondents (Years)	12.0	2.9	7.0	16.0
Share of income from agricultural activities (%)	55.8	32.5	0.0	100.0
Total area of land owned by respondents (ha)	4.6	3.9	0.5	16.2
Total number of people working on the farmland	9.8	4.6	4.0	20.0
Age of BGP since its installation (Years)	1.9	0.6	1.3	2.8
Duration of operation of BGP (Hours)	2.0	1.0	1.0	4.0
Total number of cattle owned by the respondents	29.6	29.1	4.0	105.0

5.3 Testing of Hypotheses

The hypothesis was statistically analyzed using the Pearson correlation matrix, where the maximum amount respondents are willing to spend on BGP repairs is significantly dependent on their share of income (in %) from agricultural activities. That is, the statistical analysis revealed that there is moderate positive correlation ($r = 0.38$) at 10% significance level between the analysed independent variables. Hence, the null hypothesis H_0 is rejected in favour of the alternate hypothesis H_1.

5.4 Respondents' Satisfaction with Biogas Technology

Based on the statistical analysis, correlations across the variables determining the satisfaction of respondents' participation in the PIN biogas project are computed. The results of our correlations revealed a few significant linear relationships among the variables as presented in table 4.

Respondents' satisfaction with PIN biogas technology project is mainly influenced by gender, share of income from agricultural activities, willingness to spend on BGPs repairs, access to extension agents, experience with BGP technology and number of cattle owned by the respondents as revealed in this study. Among the determinants, the number of cattle owned by the respondents showed the strongest relationship with the share of income from agricultural activities. This demonstrates the need to have more livestock; as it is perceived that the larger a farmer's share of income from agricultural activities, the higher the purchasing power to acquire mere livestock to obtain the required quantity of feedstock for the proper functioning of the small-scale biodigester. The PIN biogas project primarily targeted participants with stabled animals purposely for the easy collection of animal manure to feed the biodigesters and to realize the full satisfaction from the technology.

Similarly, respondents' satisfaction with the technology was found to be positively influenced by the maximum amount (in US$) that respondents are willing to spend on BGP repairs. This was revealed to be significant at the 5% significance level. This means that respondents' willingness to spend on BGP repairs is an important determinant to respondents' satisfaction on the biogas technology implemented by PIN in Zambia.

Table 4. Corresponding Relationships of Variables Determining Biogas Users Satisfaction with Biogas Technology

Variables	**Statistical test**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**
Gender (a)	Pearson coefficient	1.00							
	p-value								
	N	20							
Education (b)	Pearson coefficient	-0.33	1.00						
	p-value	0.16							
	N	20	20						
Share of income(c)	Pearson coefficient	0.20	-0.28	1.00					
	p-value	0.39	0.22						
	N	20	20	20					
Willingness to pay for BGP repairs (d)	Pearson coefficient	**0.51***	-0.34	**0.38****	1.00				
	p-value	0.02	0.15	0.10					
	N	20	20	20	20				
Extension contacts (e)	Pearson coefficient	0.00	0.31	0.09	-0.22	1.00			
	p-value	1.00	0.19	0.72	0.36				
	N	20	20	20	20	20			
Total farm area (f)	Pearson coefficient	-0.31	0.34	-0.05	-0.31	0.27	1.00		
	p-value	0.19	0.14	0.84	0.18	0.26			
	N	20	20	20	20	20	20		
Experience with BGP (g)	Pearson coefficient	0.16	-0.44	0.11	0.25	**-0.48***	-0.36	1.00	
	p-value	0.50	0.05	0.64	0.29	0.03	0.13		
	N	20	20	20	20	20	20	20	
Number of cattle (h)	Pearson coefficient	**X**	-0.47	**0.58***	-0.39	-0.19	-0.08	0.08	1.00
	p-value		0.12	0.05	0.21	0.54	0.81	0.53	
	N		12	12	12	12	12	12	12

Note: * and ** represent correlation significance at 5% and 10% levels respectively and **X** shows that one of the variables is a constant and cannot be computed.

Respondents' satisfaction with biogas technology under the PIN biogas project is also influenced by their access to extension agents. The extension agents referred under this project include facilitators, mediators between BGP owners (participants) and project implementers. Surprisingly, a correlation between the respondents' access to extension agents and their experience with biogas technology revealed a negative significant relationship at 5% significance level among the respondents. This could be because of the poor influence of facilitators of the project (builders, masons, repairers) on the choice of materials or components for the construction as well as malfunction of the BGPs. In addition, the negative correlation could be explained by the non-responsive attitudes of builders (masons) and repairers during a call on them by BGP owners who are faced with some technical and operational challenges with their plants.

The respondents were also interviewed based on their levels of satisfaction and requirements for the proper functioning and use of biogas plants in the region. Figure 3 presents the responses of the respondents to statements regarding their levels of satisfaction to biogas production for cooking, requirements on biogas plant operation, economic benefits from biogas technology and time savings , thanks to biogas technology.

Again, analysis based on the questionnaire data revealed that majority of the project respondents 90% (18) of the respondents had some experience with biogas technology trainings. These trainings were provided by jointly PIN and SNV (in 83.3% cases) and solely SNV (in 16.7% cases); while the rest 10% of the respondents had no experience with biogas technology training.

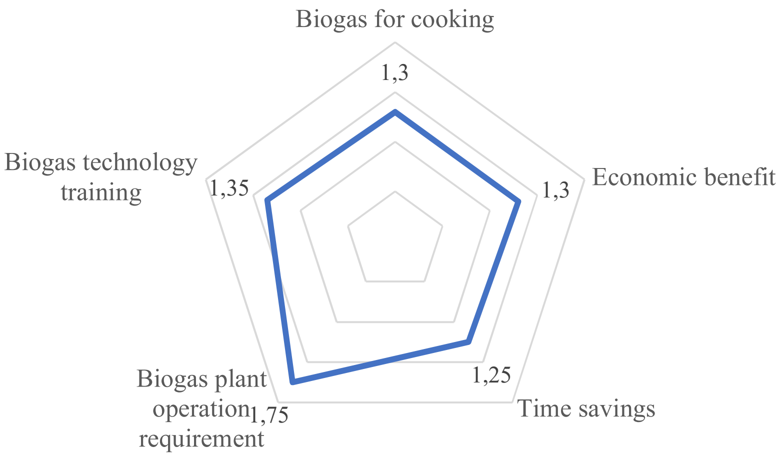

Figure 3. Satisfaction of Biogas Users in Various Aspects - measured in Weighted Score (n = 20), 5-point Lickert scale (1-very satisfied, 5-very dissatisfied)

Furthermore, participants were interviewed on their overall satisfaction regarding biogas technology trainings they have received. From figure 3, it is obvious that the overall satisfaction of the respondents concerning their participation in biogas technology trainings is very satisfied with a weighted average score of 1.35. It is important to note that, the survey did not capture the frequency of the trainings that could reveal the intensity of the trainings.

Responses to statements regarding biogas users' satisfaction to biogas production for cooking and the economic benefits (Table 5) they derive from biogas technology from the survey established that, 75% (15 respondents) were very satisfied, 20% (4 respondents) were satisfied and only one (1) respondent was neutral to the use of biogas for cooking and the economic benefits obtained from biogas technology. Overall satisfaction of the respondents to biogas production for cooking and the economic benefit from the technology is revealed to have a weighted score of 1.3 for each statement and shows that the participants were generally very satisfied with the intension of producing biogas for cooking within the province and the economic benefits they gain from biogas technology. The respondents' overall satisfaction level to this statement had a weighted score of 1.75, which explains that the respondents were generally satisfied with the requirements on biogas plant operation. Finally, the respondents' reactions to time savings on the use of biogas technology revealed that sixteen (16) respondents denoting 80% were very satisfied with time savings on the use of biogas technology, whereas three (3) of the respondents making 15% were satisfied and one respondent reacted indifferent to time savings, thanks to biogas technology. The weighted average score for this statement was 1.25, which shows the respondents were generally very satisfied with the time saved on the use of biogas technology. Generally, the level of satisfaction of the respondents of the biogas project revealed a weighted average score of 1.40 which still indicates very satisfied reactions to the overall satisfaction of biogas project in Western Zambia.

Table 5. Satisfaction of Biogas Users (n = 20)

Statements	Very satisfied (1)	Satisfied (2)	Neutral (3)	Dissatisfied (4)	Very dissatisfied (5)	Weighted Score
	Frequencies (%)					
Biogas for cooking	15(75)	4(20)	1(5)	0(0)	0(0)	1.30
BGP operation requirement	6(30)	13(65)	1(5)	0(0)	0(0)	1.75
Economic benefit	15(75)	4(20)	1(5)	0(0)	0(0)	1.30
Time savings	16(80)	3(15)	1(5)	0(0)	0(0)	1.25
Overall satisfaction with biogas technology						**1.40**
Overall satisfaction with biogas technology trainings	15(75)	3(15)	2(10)	0(0)	0(0)	1.35

In comparison, it can be deduced from figure 3 that, respondents of the biogas project in Zambia were very satisfied with biogas production for cooking and the economic benefits from biogas technology, followed by time savings, thanks to biogas technology and lastly followed by the requirements on biogas plant operation.

5.5 Technical and Operational Challenges Perceived by BGPs Users

The study revealed that 75% (15) 0f the respondents have experienced some challenges with the biogas technology. In all the six main subsystems of BGPs, the users of this technology were confronted with challenges in various forms. The highest average occurrence of problems was revealed to have occurred in the anaerobic digestion (AD) process and biogas production subsystems, followed by problems in the biogas utilization equipment subsystems, digestate disposal subsystems, structural components, piping system, biogas-knowledge-related problems, and other non-technical problems respectively as shown in table 6.

Table 6. Main Challenging Subsystems of the Small-scale Biogas Plants (n = 20)

Main subsystems	Average occurrence of challenges (%)
Anaerobic digestion process	47.3
Biogas utilization equipment	11.6
Digestate disposal system	11.0
Structural components	10.0
Piping system	8.9
Knowledge related challenges	6.9
Other non-technical challenges	4.8

The main technical and operational failures that occur in the various subsystems of BGPs with their frequencies of occurrence among the small-scale BGPs owners are presented in table 7.

Table 7. Main technical and operational failures associated with small-scale BGPs owners (n=20)

Main challenges with BGPs (Subsystems)	Challenge description	Frequency of appearance
Anaerobic digestion process	Leakages in reactor	15
	Breakdown of AD process	13
	Lack of feedstock (oversized BGPs)	12
	Solid digestate floating in tank	11
	Lack of biogas	10
	Smell of biogas	5

	Oversupply of biogas	3
Biogas utilization equipment	Malfunction of biogas cookers	14
	Unavailability of biogas-powered lamps	3
Digestate disposal system	Lack of organic matter in digestate	10
	Poorly accessible reservoirs for digestate	6
Structural components	Challenges with the inlet pipe	11
	Unstable BGPs in rainy season	1
	Inconvenient position of BGPs	2
Piping system	Leakage in piping system	7
	Blockage of piping system	5
	Lack of technology knowledge by BGPs owners	1
Knowledge related challenges	Unsatisfactory knowledge by BGP owners	7
	Unsatisfactory knowledge of masons by BGPs owners	3
Other non-technical challenge	Breeding grounds for insects (mosquitoes)	3
	Lack of finance	3
	Lack of land	1

6. Discussions

6.1 Theoretical Biogas Potential from Animal Dung

The estimated theoretical value of biogas potential from animal dung is equivalent to a volume of 2.671×10^{12} m^3 of biogas per year. In Zambia, the average household size is five (5) members (Scherbov et al. 2020), and each household requires 3 m^3 of biogas for cooking and lighting purposes (Kasali 2008). This estimated theoretical volume of biogas could serve more than three million households if the biogas requirement for each household is 3 m^3 of biogas per day for cooking and lighting purposes, which is consistent with findings highlighted by Shane et al. (2015). Therefore, it could be concluded that, the estimated theoretical biogas potential from animal dung is more than sufficient to supply the energy needs of Zambia's small-holder households. However, to be able to supply such volumes of biogas to meet the households' energy requirements in the country and to encourage the adoption of biogas, there is the need to identify and provide necessary solutions to the several challenges confronting the implementation of biogas technology.

6.2 Socio-economic Characteristics of Respondents

The findings regarding the average ages of the respondents and their average number of years of formal education conform to previous research findings which established that biogas adopters or users were averagely older and had more years of formal education (Walekhwa et al. 2009). It is therefore expected that higher education among respondents would result in a higher ease of adaptation to new innovations (Behrman and King 2001). The higher achieved education also has influence on the better maintenance of BGPs and better management of digestates used in BGPs operations.

Results on the forms of energy utilized by the respondents conform to previous studies conducted by Jürisoo et al. (2019) which, reported that the main source of energy employed in cooking throughout the rural areas in Zambia is wood fuel, which is used by more than 50% of households. In addition, Roubik and Mazancová (2020) explained that rural households continue to use wood fuels in high proportions due to its easy accessibility and affordability. These revelations, however, explain the country's growing challenges regarding deforestation as the increase in the cutting of trees for charcoal or firewood utilization and frequent fires reduce the forest cover which in the long term destroys the soils and reduces the fauna and flora species within the ecosystem (Lassauce et al. 2012). Furthermore, the findings also reveal low adoption of biogas technology among the households in the Western Province of Zambia and this could be among the reasons for the increase in the use of forest products such as charcoal and firewood among the inhabitants.

6.3 Variables Across the Respondents' Satisfaction with Biogas Technology

Respondents' satisfaction with biogas technology is positively influenced by the share of income from agricultural activities (Table 4). This explains that if farmers (participants) consider gains from the adoption of a modern agricultural production technology to have a higher potential as compared to their current production method, then they have a higher probability to adopt it and the reverse is also true. This result agrees with the observations by Abara and Singh (1993) who found that if the difference in outcomes between two alternatives is higher; that is if the returns from the alternative and conventional practice is higher, then the likelihood that small-scale farmers will adopt the new practice is higher. The results of the study also informed that BGP owners are farmers who have the capacity to support the construction of the BGPs as the installation (construction) and maintenance of the BGPs involve some costs. In Zambia, renewable energy technologies cost more than the average income of households in the country (Mfune et al. 2008). After assessing the locals' financial positions, they were not able to bear the full cost of installing a biogas digester, hence the beneficiaries were asked to contribute either in cash or kind (molding of bricks, feeding the builders, assisting in the digging of digester pits, providing water during the construction). The remaining costs were then incurred by donors. Mostly in the rural areas of Zambia, the financial inability on the part of farmers to adopt and implement biogas production has led to high poverty incidence among households; as they rely on the traditional sources of energy which has lots of inefficiencies (CSO report 2012).

6.4 Technical and Operational Challenges Perceived by BGPs Users

The possible causes, solutions and recommendations to the problems confronting BGPs users are described and analyzed from the most prevalent to the least prevalent as follow.

6.4.1 Problem Analysis: Anaerobic Digestion (AD) Process

The main subsystem of BGPs with the highest incidence of challenges confronting small-scale BGP owners was the **AD process and biogas production subsystem** with the highest occurring frequency of 47.26% (69 cases). The main purpose of installing BGPs is to produce biogas for energy through AD process and this subsystem is responsible for this process. Several requirements including but not limited to temperature, pH, nutrients, micro-organisms concentration, the absence of oxygen must be followed during biogas production. Overlooking the adherence of these requirements would pose a threat to the process and hence render its effectiveness null (Thu et al. 2012).

In this category, the most common challenge with the small-scale biogas system among the BGP users in the area was **leakages in the reactor**. This problem appeared in 15 cases (21.74% of cases under the category). Leakages in reactors can occur from multiple factors including but not limited to unskilled masons (poor construction), high pressures in digesters, use of poor-quality building materials as highlighted in some studies from Africa (Lam and Heegde 2012) and Asia (Cheng et al. 2014, Chang et al. 2011).

Breakdown of AD process, which appeared in 13 cases (18.84% of cases under the category) was revealed as the next prevalent challenge under the category. All the challenges expressed in table 8 can result in this problem, hence the solutions suggested to these factors can help solve the problem. Another problem (third most common challenge) confronted by BGP users in the target area associated to this category was the **lack of feedstock**, mostly connected to over- or under-sized BGPs, which appeared in 12 cases (17.39% of cases under the category). Occurrence of this problem is mainly due to the reduction in the number of livestock (for example, due to the sale of animals to cater for financial household needs) kept by farmers. This reduces the sufficiency of animal dung (organic manure) needed for the proper functioning of the BGPs. Irregular feeding of livestock can also lead to this problem as excrements from animals is lowered (Singh and Sooch 2004, Thu et al. 2012). The over-sizing of BGPs leads to under-supply of biogas (leading to improper functioning of BGPs) whereas under-sizing of BGPs is associated with over-supply of biogas, which leads to atmospheric pollution as excess biogas is released into the atmosphere, a common practice in most areas (Roubik et al. 2016). This released excess biogas contributes to global warming. This is because methane gas, which is a fundamental greenhouse gas is a component of biogas (Mata-Alvarez et al. 2000).

To eliminate this problem of over-sizing and under-sizing of BGPs, it is appropriate that facilitators and masons (builders) consider and familiarize themselves with the current economic situation of prospective BGP owners to provide appropriately sized BGPs that meet their needs.

Further challenges emanating from **solid digestates floating in the tank** appeared in 11 cases (15.9% of cases under the category). The formation of a solid scum layer on the surface prevents the flow of biogas through the BGP and ceases the system from functioning (Roubik et al. 2016). Often opening the BGP and removing the solid surface is the way forward when such problem occurs.

The next challenge in this category is the **lack of biogas**. It appeared in 10 cases, representing 14.5% of cases under the category. This problem is linked to low concentration of methane, which renders the quality of the biogas very poor. It can also be linked to insufficiency in the supply of feedstock and breakdown in the AD process (Thu et al. 2012).

The **smell of biogas** appeared in 5 cases (7.3% of cases under the category) and was identified among BGP users who do not possess desulfurization unit (for example hydrogen

Sulphur, H_2S) or that did not properly maintain the unit. Properly using and maintaining the desulfurization unit is a simple solution that must be transferred to BGPs users through facilitators (Rubik et al. 2016). Finally, problems associated with the **over-supply of biogas** was the last under this category with 3 cases (4.4% of cases under the category). The possible causes and solutions are already provided above in connection with the under-sizing of BGPs, which is associated with over-supply of biogas.

6.4.2 Problem Analysis: Biogas Utilization Equipment

The second highest incidence of challenges confronting small-scale BGP owners was identified in the category of **biogas utilization equipment** with 17 cases (11.6% of all cases in our survey). **Malfunction of biogas cookers** appeared in 14 cases, which also recorded the second most prevalent failure among the respondents in our survey as represented in table 6. This result corresponds to discoveries of Roubik et al. (2016), who also explained that failure of biogas cookers to function correctly can be due to several occurrences and failures including corrosion, damages on the gas tap, damages on flame pedestals or blockage in the air injectors. The use of Hydrogen Sulphur (H_2S) filter is appropriate to aid in the prevention of corrosion, whereas properly regulating the fire to suitable levels and properly maintaining the cooker or using higher quality cookers can help resolve these challenges. These highlights comply with those found in other studies, specifically Pipatmanomai et al., 2009; Thu et al., 2012; Cheng et al., 2014 and Roubik et al. 2016. **Unavailability of biogas-powered lamps** was the second problem identified under this subsystem category with 3 cases. Respondents linked the high cost of the lamps and long distances from their locations to the marketplaces where these lamps can be purchased (accessibility issues) to this challenge. In Zambia and other SSA countries, electricity power supply is not accessible to all; especially in the rural areas. Hence making available lamps that can be powered by biogas to the inhabitants will increase their interest and participation in the use of biogas technology. In addition, the high cost of electricity relative to the cost of using biogas in such countries will arouse the interest of the communities to partake in the technology.

6.4.3 Problem Analysis: Digestate Disposal System

The third highest appearance of challenges identified in this survey was revealed in the **digestate disposal system** with 11.0% average occurrence of challenges (16 cases). Challenges encountered under this system in our survey are **lack of organic matter (OM) in digestate** (10 cases) and **poorly accessible reservoirs for digestate** (6 cases). Excessively high proportions of water and manure mixtures can lead to lack of OM in the digestate, which can affect digestate quality required for fertilizer production (Li et al. 2012; Mwakaje 2008). The use of the digestate as fertilizer has several advantages compared to raw manure (Nkoa 2014; Thy et al. 2003) and chemical fertilizers (Panuccio et al. 2021; Lukehurst et al. 2010), as it can improve soil fertility (Alburquerque et al. 2012) and reduces the use of non-renewable energy and carbon dioxide emissions (Li et al. 2012). To curb this challenge, it is appropriate that BGP owners undergo trainings focused on the use of adequate proportions of water during the mixing process.

The second problem encountered under this category is **poorly accessible reservoirs**, which contributes to underused digestates. The improper positioning of reservoirs causes this problem as well as several other digestate management problems (Roubik et al. 2016). Hence, properly building and placing the reservoirs in the appropriate position is the sole responsibility of facilitators and masons (builders) and can prevent occurrence of this problem.

6.4.4 Problem Analysis: Structural Components

From our survey, the average occurrence of problems in the **structural components' subsystem** of BGPs was 14 cases (9.59%). The most occurring problems among the respondents under this category were challenges with the **inlet pipe** (11 cases), **inconvenient position of BGPs** (2 cases) and **unstable construction of BGPs** in the rainy season (1 case). Problems linked with the inlet pipe emerged the most frequent problem identified in our survey, and it agrees to research findings from other studies by Roubik et al. (2016) and Cheng et al. (2014). Inappropriate slope in the inlet pipe can lead to organic manure not reaching the digester and this presents the main cause of this problem. Further, blockages in the inlet pipes can be cleared with flowing water or a long stick (Roubik et al. 2016).

Inconvenient positioning of BGPs was the second most occurring challenge under this category from our survey. Such inconveniences may include but not limited to the proximity of BGPs from the animal pens or farms and the free-range system of keeping animals in the study area. This presents poor accessibility to feedstock (animal manure) and additional difficulties in the operation of BGPs as it takes BGP owners in the area more than eight (8) hours daily to go about collecting the animal dungs spread in different locations. Thirdly, **instability in the construction of BGPs** during the rainy season is identified under this category in the survey. Unskilled workmanship on the part of builders (masons) is mainly the cause of this problem as it is a prerequisite to have well trained or skilled builders in the construction of BGPs that can function well under all conditions (Roubik et al. 2016).

6.4.5 Problem Analysis: Piping System

The next identified challenges were linked to the piping system of BGPs with 6 cases (8.90%). The most frequent challenge under this category in our survey were linked to **leakages in the piping system** (5 cases) and **blockage of the piping system** (1 case). As described by Sovacool et al. (2015), leakages in the piping system could result when the pipe is not properly connected, or the connections between the pipe and valve or the pipe and nipple are not properly fixed. Corrosion of the gas pipe can also cause leakages. It is therefore recommended that the pipeline be entirely replaced if necessary or be repaired by a skilled builder. Blockage of piping system was also described to occur when the pipeline is abandoned for a long time unused. Water condenses in the pipe when there is no water filter in the pipeline (Cheng et al. 2014).

6.4.6 Problem Analysis: Knowledge Related Challenges

The implementation of any technology requires proper and adequate understanding of its operations and importance. Problems under this category among our respondents occurred in 10 cases (6.85%). **Unsatisfactory knowledge on biogas technology** by BGP owners occurred more frequently among the respondents (7 cases), followed by **unsatisfactory knowledge (skills) of builders (masons)** as mentioned by BGP owners (3 cases). Similarly, knowledge-related problems on biogas technology have been highlighted in other studies and the importance of this knowledge and how it is transferred from facilitators to beneficiaries are described vividly (Zhou et al. 2011; Uddin and Mezbah-ul-Islam 2012; Agyenim and Cupta 2012; Roubik and Mazancova 2014). It is of essence to effectively inform BGP owners on the technology to ensure the proper functioning, maintenance, and sustainability of the technology.

6.4.7 Problem Analysis: Other Non-technical Challenges

There are several other problems, referred to as non-technical challenges, that affect the operations of BGP owners. The most profound among them was the **proliferation of insects**, specifically the female *Anopheles mosquitoes*. This occurs when the digester is left opened and when the chamber stores water after rains it breeds such insects which can result in malaria outbreak in the area (Roubik et al. 2016). Other challenges include **lack of finance** on the part of BGP owners **to maintain and repair their BGPs** and the challenges with **land availability** as identified through our survey. However, other non-technical which were not mentioned by our respondents may include cultural and social issues which include the stigma attached to the use of human excreta as feedstock for BGPs.

7. Conclusions and Recommendations

The main objective of this study was to estimate the biogas potential from livestock manure in Zambia through the development of small-scale biogas plants. The population of livestock is adequate to supply the required volumes of organic manure (feedstock) for biogas production in Zambia. In the Western Province of Zambia, the use of biogas technology is suitably supported by the sufficient supply of feedstock produced from animal waste, with an estimated theoretical biogas potential of 57,874 TJ per year, which can supply the entire energy needs of Zambia's households.

Small-scale BGPs can play significant roles in farming systems and can convert oranic waste including livestock manure to fertilizer (value addition). Several other significant advantages can be offered by this technology, especially in the areas of energy provision, economic and environmental development. Respondents' satisfaction with the technology is mostly linked to the support provided by the facilitators of the project. To fully understand and examine the technical and operational challenges confronted by BGP users in the study area, small-scale biogas technology was categorized into six subsystems namely anaerobic digestion process, biogas utilization equipment, digestion disposal system, structural components, piping system and knowledge related challenges. The study revealed that 75% of the respondents had experienced some challenges with the biogas technology, especially regarding the technical and operational aspects of the technology.

In conclusion, the study presented an analysis of challenges confronted by BGP users within the Western Province of Zambia. The study highlighted solutions and recommendations to solve the challenges identified among the BGP users regarding the technology and further proposed the following specific recommendations based on the findings of this study:

1. There is the need for further studies regarding the eradication of challenges encountered from the use of this technology.
2. Further research is required to reveal health-threatening potentials regarding the use of BGPs and to provide alternative ways of using BGPs in developing countries, especially among SSA countries.
3. Facilitation regarding the use and operation of this technology is recommended to enhance its effectiveness for end users.
4. The study also recommends the need for further education and training aligned with the technology (for both BGP users and builders) and aided by frequent technical or extension visits.
5. Improvements in the skills of extension agents, as such skills could impact the training of participants (BGPs owners), masons who build and repair the BGPs.
6. The construction of the BGPs should be expanded to include many people within the province as many have expressed interest in the technology.
7. Adequate credit systems should be provided for farmers to increase their livestock capacities and animal housing.
8. Exemptions on taxes should be introduced on appliances (for examples biogas cookers, biogas powered generators and lamps) which are purposely designed for biogas plants.
9. Farmers who have integrated biogas technology into their farming activities should be encouraged by providing them with subsidies.

10. There is the need for further research on the use of other feedstock resources such as forests residues and agricultural residues with potential to produce biogas in the study area.

Findings from this research will be useful to the international, national, and local authorities, particularly policy makers, project designers and facilitators.

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