The Use of Biogas Energy for Electrical Power Generation in Zimbabwe—A Study

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1 Introduction

Zimbabwe has been facing an energy crisis since the country's independence in 1980. This is mainly due to the fact that the economy of the country has been expanding, but the capacity of the generating power plants has remained almost constant. Zimbabwe relies significantly on hydroelectricity and thermal power. The biggest hydroelectric power station of the country by installed capacity is Kariba which generates a total of 1626 MW located on the perennial river Zambezi. It has been the largest producer of electrical power supply in the landlocked country that relies on importing electricity from neighboring countries. Due to a lot of difficulties that have been faced by these power plants which include lack of service, depletion of water levels, increased cost price of fossil fuels, and poor workmanship, Zimbabwe has faced erratic power supplies and experienced a lot of load shedding over the years [1, 2].

Anaerobic digestion of organic matter produces biogas. The combustible gas is produced when feedstock like manure from animals, sewage, and forestry is fed into the biogas digester in the absence of air [3–16]. In most third world countries, biogas is being used for cooking and lighting because of its efficiency and clean nature, realizing the gas' potential for electricity generation on a large scale could be a huge milestone in Africa. This can minimize the stress on the electrical grid and also provide electricity for the rural population of Zimbabwe where the grid is not extensive. This technology is very promising in Zimbabwe; agriculture is a key component of the country's economy. This is an advantage since a lot of substrates will be available to feed into the digesters. Despite the field being largely untapped, there is not a single biogas plant that generates electricity in the country, which is shocking. Biogas has been regarded as one of the cheapest sources of renewable energy for generating

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electrical power by many research centers and international bodies. When compared with solar energy and wind power, biogas has an advantage over the two because it is not intermittent; therefore, it can generate electrical power at any time be it night or day as long as sufficient substrate is available [4, 5]. Acquiring feedstock does not pose any environmental threats since it can easily be accessed from agricultural residues and even kitchen organic waste. Farmers in the rural areas can make extra money by supplying feedstock to the local biogas plants within the vicinity. There has been little or close to zero experience of implementing these biogas plants to generate electricity in the rural parts of most African countries. Biogas has similar uses to natural gas in engines, for cooking and for lighting [15]. It is a mixture of a few gases with the main gas being methane which is combustible, carbon dioxide, water vapor, and sulfur compounds. The efficiency of biogas depends on the percentage of methane in it. The more methane there is the more the efficiency. Carbon dioxide and water vapor cannot be eliminated entirely, but the content of sulfur should be less. A lot of sulfur content can be damaging to the engine. Approximately, 6kWh of electrical energy is produced by 1 m^3 of biogas [17]. Factors affecting the yield of the biogas plants are retention time, type of feedstock, fermentation temperature, and plant design [6, 7]. This paper demonstrates the research methodology used by the researcher, analyzes the results obtained, and finally concludes with a discussion.

1.1 Literature Survey

Studies of this sort have been conducted by few scholars in Zimbabwe. Mukumba et al. (2013) studied the design of a biogas plant at a high school in the outskirts of the country. The biogas produced will be used to generate electricity. The study was conducted to mitigate power cuts due to load-shedding and also reduce the use of fossil fuels like firewood [5]. The school's energy demands were calculated and noted. The feedstock required for the project was identified to be human excreta, cow dung, and poultry manure. The quantity of feedstock to be produced per day was calculated by counting the number of people, cows, and chickens. The total amount of biogas to be produced per day was calculated, and it was observed that this would be sufficient to produce electricity for lighting in periods of load shedding. The technoeconomic analysis of the project was done, and the project was seen to be feasible. This project however was only focused on Nyazura Adventist High School. Garikai and Daniel (2019) studied the status of most biogas digester plants in rural Zimbabwe. Four common types of biogas digester plants were found to be common, and these included Indian type, Chinese type, bio-latrine type, and Carmatec type [3]. 126 biogas digesters were visited, and only, 14 were found to be functional. Most of the biogas digesters did not have proper gas pipes, temperature control and monitoring mechanism, flow meters, heating systems, etc. In Africa, there is only one biogas plant that generates electricity which is grid connected. This biogas plant which was launched in August 2015 is located in Naivasha, Kenya. The Gorge Farm Park has a capacity of producing 2 MW of power. The plant does not only produce electricity but also produces heat for the farm's greenhouses and fertilizer and as a byproduct. The plant uses Jenbacher gas engines which are of Austrian origin and manufactured in the town Jenbach. The plant was developed by Tropical Power which is incorporated in the United Kingdom and has a subsidiary in Kenya.

2 Research Methodology

2.1 Research Procedure

The researcher conducted a literature survey to get an overview on the operation of biogas digester plants in the country which would help determine the potential of electrical power generation. Detailed information of where these biogas plants are located has been recorded as well as the institutions and individuals responsible for the construction of the plants. To obtain this information, about the current status of the production of biogas in Zimbabwe, four sets of questions were designed and tested to check their feasibility and then applied. Proportional random sampling was used to apply the four sets of questions to the Ministry of Energy and Power Development and head office and provincial offices of Rural Electrification Agency since they are responsible for providing energy as well as monitoring all on-going projects on the generation of energy in the Southern African country. The first category of this set of questions was designed to collect information on the size, design, and number of biogas digesters in Zimbabwe. The next category of questions collected information with respect to the type of feedstock being fed in the biogas plants. The third category focused on the financing of the biogas plant system construction in the country. Next category analyzed the utilization of the biogas and substrate from the biogas plants. The last part collected information regarding the challenges being encountered in operating the plants, ways to improve the production of biogas, and the technology being used. The set of questions were directed to households and institutions in three of the provinces that were randomly selected, i.e., Harare, Mashonaland East, and Mashonaland West. The researcher was able to visit twelve biogas plants in person which were easily accessible to him.

2.2 Aim of the Investigation

The main aim of the survey was to determine the state and condition of biogas digesters in all provinces of Zimbabwe and analyze the feasibility of electricity generation from biogas.

Table 1 Areas of focus for data collection

Operational issues	Technological issues	Ownership issues
Feeding intervals	Size of digester	Year of construction
Quantity of substrate per feeding	Type of digester	Frequency of maintenance
Distance from water source	Type of sensors and valves	Owner's opinion functionality
Distance of digester from user	Material used for construction	

2.3 Data Collection Tool

The tool that was used for this survey focused on the aspects given in Table 1.

3 Results

3.1 Number of Biogas Plants in Zimbabwe

When Zimbabwe realized Biogas can be a good source of clean energy for cooking and lighting unlike firewood which is used by the greater population of rural Zimbabwe, it led to the construction of different biogas plants in the country. According to the researcher, more than 700 biogas digesters had been built in Zimbabwe by 2021. From Fig. 1, it can be seen that there is a steady rise in the number of biogas plants for the period 2013 to 2020.

3.2 Biogas Plant Types

Figure 2 classifies the different types of biogas plants with their quantity expressed in percentages. The largest number of biogas plants in the country is household digesters contributing about 91% of the total number of biogas plants in Zimbabwe. The size of household digesters ranges from 4 to 30 m^3. The biogas plants located at schools, hospitals, and prisons are regarded to be institutional digesters. They have a size which ranges from 50 to 200 m^3. A few of the biogas plants that are located at local sewage treatment facilities and market areas to process the waste are considered to be municipal digesters. Figure 2 illustrates that 7% of the total number of biogas plants were institutional and municipal biogas plants contributed 2%. It was observed that in Zimbabwe, there is no existence of industrial biogas plants.

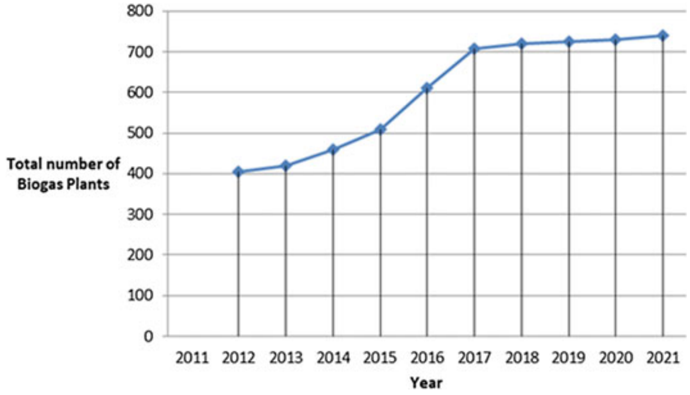

Fig. 1 Gradual increase of biogas plants from 2011 to 2021 in Zimbabwe

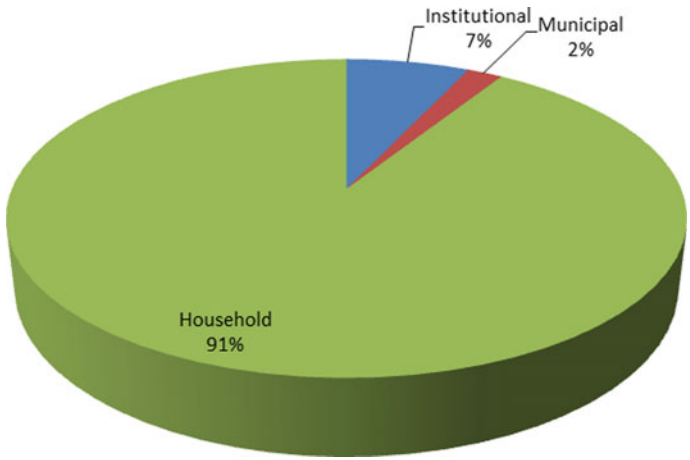

Fig. 2 Classification of biogas plants

3.3 Classification of Institutional Biogas Plants

The size of institutional biogas plants ranges from 50 to 200 m^3. Figure 3 shows how these biogas plants are distributed across the different provinces of the country.

Every province has at least one institutional biogas plant except Bulawayo. A total of 48 digesters were recorded to be institutional biogas plants.

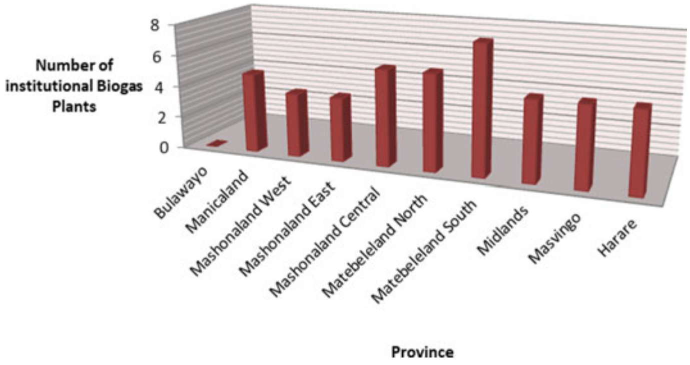

Fig. 3 Classification of institutional biogas plants

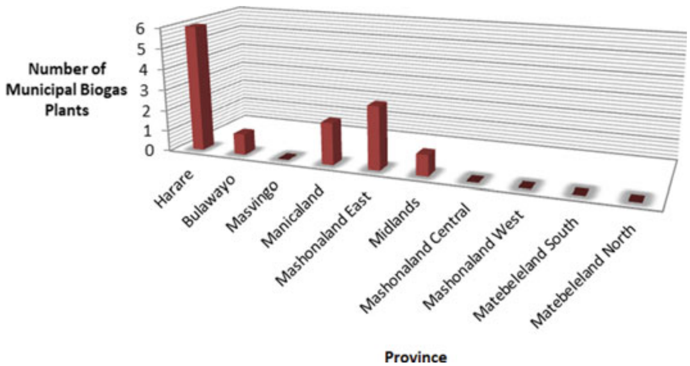

Fig. 4 Classification of municipal biogas plants

3.4 Classification of Municipal Biogas Plants

Biogas plants constructed at local municipal facilities and public market areas were utilized for the treatment of waste. Biogas from these plants can also be used for lighting, heating, and cooking by the local people. Figure 4 shows that only a few provinces have these plants. All municipal facilities across all provinces in the country should adopt this technology for sanitation purposes [14].

3.5 Substrate Used in Biogas Plants

As shown in Fig. 5, more than 90% of biogas digesters use cow dung as a substrate. A small number was using sewage 8%, and only 1% used pig and poultry manure. Kitchen waste was also being used by 1% of the owners. Owners and operators of

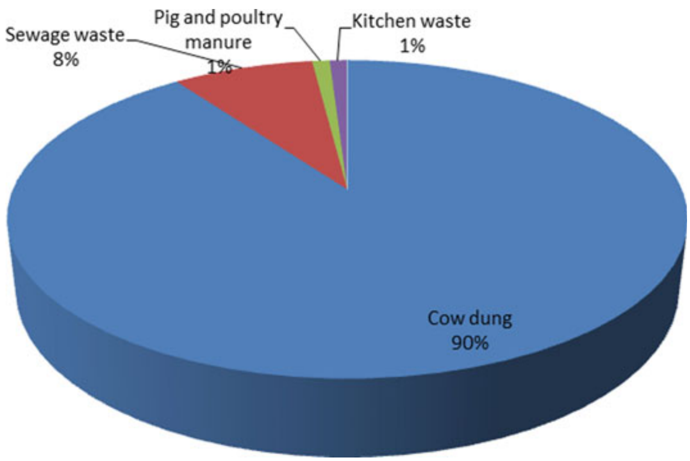

Fig. 5 Substrates for biogas plants

biogas plants should strongly consider using other substrates like forestry and plant residues [12]. The use of pig and poultry manure should also increase because they have a high energy content [13–16, 18]. This will improve the efficiency of the plants and hence increase the biogas production.

3.6 Utilization of Biogas

A large number of biogas owners were using the gas for cooking as shown in Fig. 6. A small percentage used the gas for lighting, space heating, and waste management. This shows that the technology of using biogas energy to generate electricity is still foreign in the country. Biogas can also be used as a fuel to power vehicles the same way compressed natural gas is used in countries like India.

3.7 Challenges Faced in Running Biogas Plants

Operators and owners of biogas plants in Zimbabwe were facing challenges like low gas production, lack of feedstock, and technical maintenance as shown in Fig. 7. All these problems can be solved if adequate knowledge on how to operate and maintain the digesters is provided to the owners [10]. Challenges faced should be minimum to realize full benefits from this technology [11].

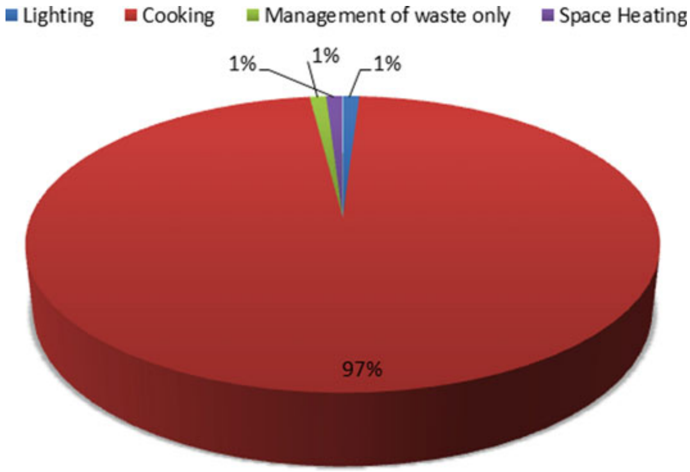

Fig. 6 Utilization of biogas

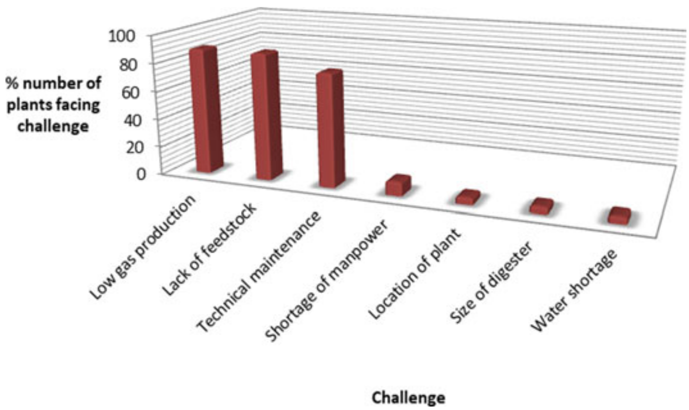

Fig. 7 Challenges faced in running biogas plants

3.8 *Proposed Process of Generating Electricity Using Biogas in Zimbabwe*

Biogas can be used as a fuel to power different types of internal combustion engines which include gas turbines, diesel engines, and gas engines (Otto motors). It can also be used to drive an external combustion engine like the Stirling motor. In most cases, internal combustion engines are used because of their high efficiency over the external combustion ones. These engines generate mechanical energy which can then be used to drive a suitable generator producing electricity. This technology is well known in industrialized countries like China and Germany. The biogas should be processed before it is pumped into the combustion engine. This is done to reduce the amount of carbon dioxide, water vapor, and most importantly sulfur compounds in the gas. The presence of sulfur elements in the gas can cause damage to the engine since the sulfur reacts with the metals in the engine. This can shorten the life span of the engine. The suitable generators required for the generation of electricity are present in almost all countries. The electricity generated can be integrated into the national grid or used by independent institutions. Suitable sensors and pumps should be used for this technology to be fully efficient.

4 Discussion

Analyses of all the results obtained by different researchers above show that it is possible to generate electrical power from biogas energy as an alternative energy source in Zimbabwe. The construction of more than 700 biogas plants in 2021 shows that the technology is being adopted in the country quite fairly. It was observed that a lot of biogas digesters were household plants with a few institutional and municipal digesters. This is a major drawback because most of the household digesters are small in terms of size and volume; therefore, the biogas produced will not be able to produce significant electrical energy to power a house. This is not to say household digesters have no use since they also generate sufficient biogas that can be used for cooking, heating, and lighting in homes. The number of municipal biogas digesters should increase because there is a huge amount of sewer that can be anaerobically fermented to produce a significant amount of electrical power that can be used by communities around. The majority of biogas digester owners and operators used cow dung as the substrate, and a few were using pig and poultry manure. A variety of feedstock should be used like plant residues and forestry to maximize the efficiency of biogas production that can be used to generate electrical power. Biogas was mainly used for cooking with a small percentage of people using it for lighting, heating, and in some cases, the biogas was just being released in the air. It is evident that the technology of using biogas to generate electrical power is foreign in Zimbabwe as is the case in most third world countries. A lot of challenges were also being encountered by the biogas owners and operators. These include lack of maintenance, insufficient feedstock to feed into the digesters, poor design of the systems, and lack of water just to mention a few. Most of these challenges can be solved by provision of knowledge to the operators; workshops should be conducted in communities to educate the general public and raise awareness. Biogas production courses should be offered in universities to educate scholars on the technology of using biogas to generate electrical power that is largely untapped in Zimbabwe and Africa as a whole.

5 Conclusion

A literature review was conducted to determine the possible electricity generation from biogas energy in Zimbabwe. At the end of the study, it is concluded that the technology is possible in the landlocked country. It has been observed that there are a decent number of biogas digesters in the country; proper education should be provided to the owners and operators so that they can experience full benefits from this alternative energy source. If proper education is provided and awareness is raised, the owners can be able to generate electrical power for homes and communities at large. The number of biogas digesters should increase in the country, especially in the rural areas since the biogas can also be used for lighting and cooking. If this technology is fully adopted in Zimbabwe, The Rural Electrification Scheme can be realized, and less stress is imposed on the grid. Furthermore, favorable policies should be put in place by the government to make this whole idea come to fruition. The proposed process of electricity generation was illustrated. The biogas generated will fuel a combustion engine coupled to a suitable generator to generate electrical power.

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