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Reduction of electricity bills by use of biogas at the University of Namibia – Rundu campus

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Abstract: Renewable energy has been identified as a viable means of securing a sustainable present and future for developing countries because of it accessibility and affordability. A lot of studies have been on biogas as a renewable source of energy, but there is little paucity on its implementation in developing countries. The social acceptance of biogas is often hampered by environmental and health concerns. This study presents a preliminary evaluation of the role and the contribution of biogas as a sustainable energy source towards cost saving and achievement of the sustainable development goals. This work reviews the different types of biogas digesters, opportunities and possibilities of producing biogas for cooking at UNAM Rundu Campus as a secondary source of energy are explored. The design criteria for optimal performance is described and explained. The most suitable model is proposed and the monetary value of the de design is also determined. A preliminary survey was carried to examine the areas where the stoves are used in the kitchen and the hostels. The population and the electricity consumption within the campus was recorded by a detailed inquiry. The data collected from the bills was used to determine the kitchen block unit power demand. The quantity of gas produced was calculated. The results show that biogas has direct impacts and contributions to the SDGs. It has the ability to increase renewable energy, reduce climate change, enhance the waste management process, and create jobs. The use of biogas for cooking reduces significantly the bills of electricity on campus. It is one of the promising renewable energy sources that can effectively reduce the environmental impact of fossil fuels.

Key words: Biogas; digester; electricity, renewable energy, SDGs

Introduction

Access to modern energy services is a requirement for sustainable development, to equip nations to accomplish their daily tasks, to excel in business opportunities and economic growth, so as to uplift the whole community particularly the population in the rural and informal settlement areas. Many developing and developed countries are facing electricity scarcity. This situation is also worsened by the rapid population growth, industrialization and urbanization resulting in high demand of electricity supply (Remmert, 2020). The demand for energy services is anticipated to increase quickly in Africa, according to the IEA (2022), hence ensuring affordability is a top priority. The demand for energy in Africa as of 2019 was 700 Terawatt-hours (TWh), with more than 500 TWh being consumed by South Africa and the nations of Northern Africa. According to the SAS (sustainable African Scenario) IEA (2022), as its population and earnings rise, the demand for modern energy will rise by a third between 2020 and 2030. The need for alternative energy sources, particularly renewable sources, has come into sharper emphasis as a result of rising electricity costs and consumption, rising population, and a growing middle class. According to Weforum (2022), renewable energy has the potential to have considerable socioeconomic advantages for a wider range of people in Africa in addition to being environmentally friendly, frequently cheaper, and widely available. This is particularly clear in Namibia, which for a long time relied on power imports from South Africa (ESKOM), but the country's own economy has made it more difficult for it to generate electricity at home and, consequently, to export. Namibia's power purchase agreement with ESKOM, which is set to expire in 2025, has been replaced by power purchase agreements with utilities in Botswana, Zambia, Zimbabwe, and the Democratic Republic of the Congo (DRC). Long-term energy self-sufficiency for Namibia is a goal shared by the government and Nampower (and one that will eventually see the country become a net exporter of power). Long-term energy self-sufficiency for Namibia is a goal shared by the government and Nampower (and one that will be achieved by adding new generation capacity). The amount of electricity generated is still insufficient to meet all of the country's needs, despite the government's efforts, and the amount of power distributed to the public is rising every year. It is therefore important to educate people on how to use wisely the ressources that are available. This study focused on UNAM Rundu campus which is situated in the Kavango region and has a population of approximately 2000 students. The bills recorded from the municipality are usually high as electricity is consumed in hostels and especially in the kitchen. There is a need for alternative electricity supply in order to reduce the costs. One of the options is to produce biogas with food waste from the campus as it is currently disposed of by Rundu municipality and use it for cooking instead of electric stoves. This will at the same time prevent the burning of waste which leads to air and water pollution. Biogas consists of anaerobic fermentation of organic matter by certain microorganisms. In anaerobic fermentation, organic wastes of domestic, agricultural and food industry have been used in biogas reactors and can be used directly for heating and electricity production. It is considered as a source of renewable energy due to continuous production of waste. In general, all type of biomass can be used as a substrate if they contain carbohydrate, proteins, fats, cellulose and hemicellulose as main components (Sadia et .al, 2020). Biomass resources should not be disposed of carelessly; instead, they should be exploited to produce clean energy rather than harm the environment.The various types of biogas digesters are discussed in this study, and opportunities and potentials for producing biogas for cooking at the UNAM Rundu Campus as a secondary source of energy are investigated. It describes and explains the design requirements for the best performance. The best model is suggested, and the cost of the design is estimated as well.

Methods

Anaerobic digester

Biogas is created when methanogens, which are a naturally occurring component of the geochemical carbon cycle, biodegrade organic material in anaerobic (without air) conditions. It is a type of biofuel that is created spontaneously through the breakdown of organic waste, such as food scraps and animal manure, in anaerobic conditions. They emit a variety of gases, primarily carbon dioxide and methane (Mussoline & Wilkie, 2017). Additionally, these organic components are recycled via anaerobic digestion in biogas systems to create biogas, which contains both energy (gas) and beneficial soil products (liquids and solids). A biogas digester is a device that converts garbage into biogas instead of releasing methane gas into the atmosphere so that the energy can be used constructively. (Larsen, 2020).

Design criteria for optimal performance

Numerous variables, including the state of the reactor's interior and exterior, its design, and its operational parameters, have an impact on the stability of the anaerobic digestion process. The operational parameters should be identified and controlled in order to ensure a steady, effective, and sustainable biogas production.

Different types of Biogas Digesters

There are many different types of digesters, of which can be organic digesters. (Muttapa, 2017), have listed the following anaerobic digesters namely; fixed dome digester, floating drum digester, bag bio-digester, plug flow digester and portable biogas digester.

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Fixed dome digester

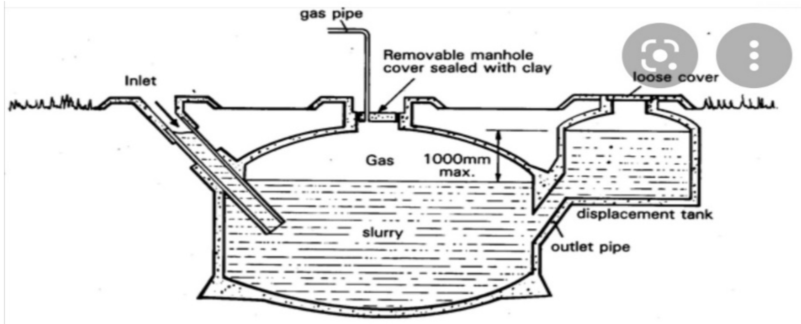

Figure 1: Fixed dome digester (Muttapa, 2017)

The fixed dome digester is easy to build, has relatively cheap construction costs, and is free of moving parts and rust-prone steel components. It has a large span if it is built well. The digester is shielded from temperature variations and saved area thanks to the subsurface construction. Additionally, the dome-shaped roof serves as a gas storage space and has a pipe outlet at the top to provide gas to residences. However, it demands highly technical expertise for gas-tight construction, is challenging to fix in the event of a leak, calls for bulky building supplies, and the volume of gas produced is not immediately apparent (Muttapa, 2017).

Floating drum digester

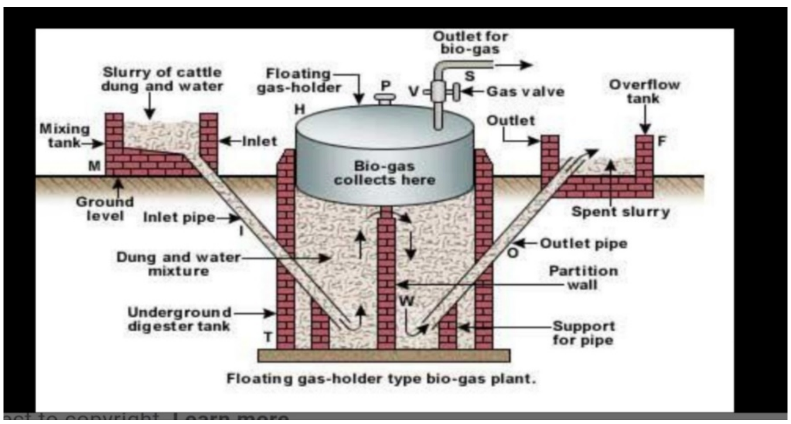

Figure 2: Floating drum digester (Muttapa, 2017)

Operation of a floating drum digester is straightforward and simple to comprehend. It delivers gas at a consistent pressure, and the placement of the drum makes the amount of stored gas obvious. Gas tightness is not a concern as long as the gasholder is regularly de-rusted and painted. Additionally, the floating has welded supports that will aid in the rotational breaking up of scum. Additionally, the dangers of combining oxygen with the gas to create an explosive mixture are also reduced, and ultimately, it would produce more gas. This kind, however, has high material costs due to the additional steel drums, a limited lifespan due to the steel drum's corrosion, and high maintenance costs due to the drum's frequent painting.

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Bag bio-digester and plug flow digester

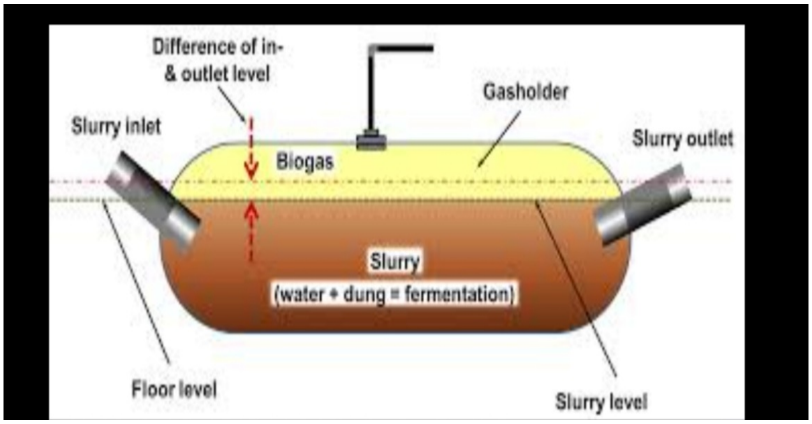

Figure 3: Bag bio-digester (Muttapa, 2017).

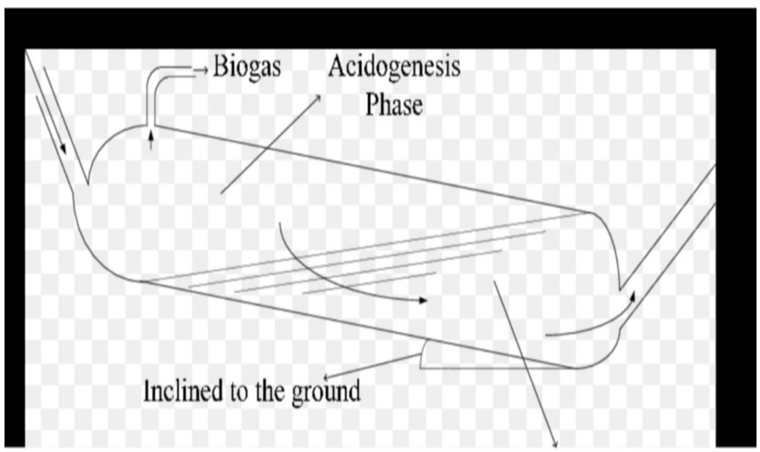

Figure 4: Plug flow digester (Muttapa,2017)

Bag bio-digesters and Plug flow digesters are both inexpensive, simple to move, have simple construction, require little maintenance, and are less susceptible to climate changes than permanent dome kinds. However, they are less environmentally friendly, have a short lifespan, poor gas pressure, and a large environmental effect.

Portable biogas digester

Fiber Reinforced Plastic (FRP) is used in the construction of mobile biogas plants. It can easily be built on a modest scale and requires locally accessible materials, many of which are sold in stores like Build-it, Mega-build, and other stores. The building procedure is straightforward, manageable, and economical. The materials for this portable biogas digester are less expensive than those for the other biogas digester, and it is simple to construct.

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Figure 5: Portable biogas digester (Muttapa, 2017)

Setting

The descriptive stepwise procedure used in this study is shown below.

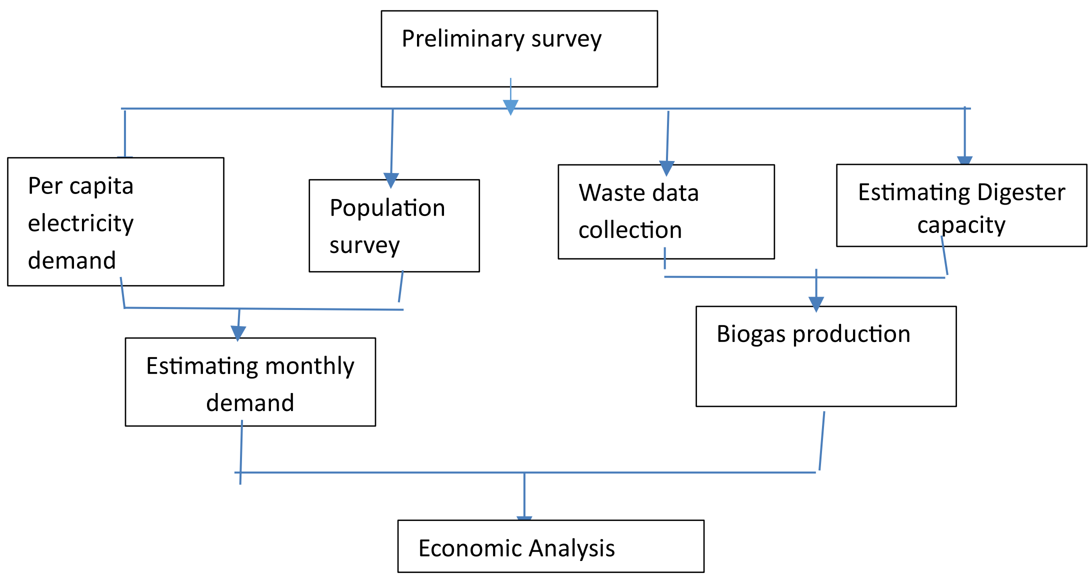

Figure 6: The descriptive stepwise procedure

Rundu campus has a population of 2 319 students, whereby the hostel accommodates 270 students and it has 20 staff housing. Organic waste such as food waste is produced from the campus kitchen, hostel as well as lecturers' houses. We engaged cleaners on the side of hostel in order to find out the amount of waste they collect from there as well as from staff housing. Approximately 50 kg is collected from the hostels and 10 kg from staff houses daily. The different types of digesters discussed are very effective in producing biogas. However, based on the context of the study area, the appropriate model to be used at Rundu campus seems to be a Portable Biogas since it requires only easily and locally available materials for construction (materials are readily available in stores). Construction process is simple, manageable, requires fewer costs and long lasting. The digester has to be fenced to avoid unnecessarily visits from people within campus. The tank has to be placed on a pavement made from cement, to keep it on a flat surface. The suitable site where to build this digester on campus will be near the kitchen, approximately 22 feet (7m) away from the kitchen wall; the area is between hostel block 1 and the kitchen. This gas will mostly be used for cooking in the kitchen in order to save costs of electricity on campus.

Anaerobic digestion (AD) processes

The anaerobic digestion processes and elements based on a systemic food supply chain perspective are shown in Fig. 7.

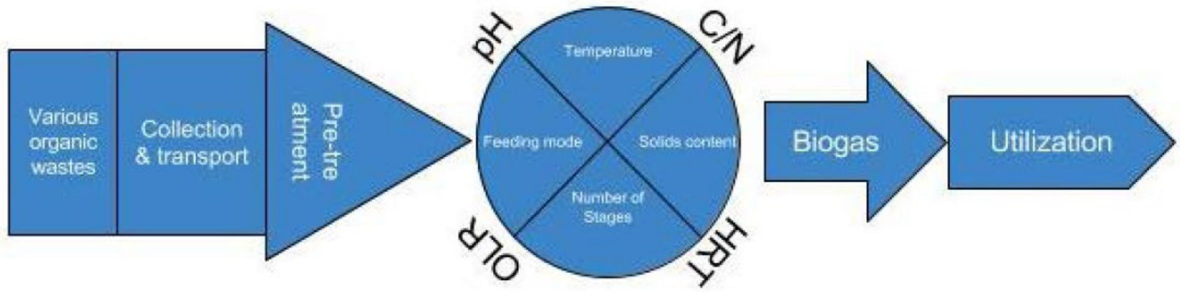

Figure 7: The supply chain of biogas production using food waste as a feedstock (Vögeli, et al. 2014).

Food waste characteristics

There are a few factors to take into account when choosing a feedstock for anaerobic digestion. The first is moisture content (weight percentage), and the second is dry matter (TS). Both organic and inorganic components can be found in the dry matter. The amount of organic dry matter, also known as volatile solid (VS), determines whether a feedstock is desirable for anaerobic digestion or not. For anaerobic digestion to be considered, the amount of volatile solid (VS) in the total matter must be at least 60% (Gkamarazi, 2015). The optimal values for anaerobic digestion are given in the table below (Tang, 2008).

Table 1: Characteristics of typical food waste (Tang, 2008)

Component	Percentage (%)
Moisture content	80.30
Total Solid (TS)	19.70
Volatile Solid (VS)	95.4

Biogas yield from Food waste

Anaerobic digestion produces biogas as its byproduct. Methane and carbon dioxide make up the majority of biogas, according to Vögeli, et al .(2014). The characteristics and makeup of the biogas produced from food waste are shown in Table 2.

Table 2: Biogas composition for food waste and the average biogas and methane yields (Vogeli et al., 2014).

Parameter	Biogas composition	Unit
Density	1.1	Kg per Nm^3
Calorific value	23	MJ per Nm^3
	6.5	kWh per Nm^3
	20	MJ per kg
Methane	65	Vol-%
Methane, variation	60-70	Vol-%
Carbon dioxide	35	Vol-%
Carbon dioxide, variation	30-40	Vol-%
Nitrogen	0.2	Vol-%
Water	2 (20°C) – 7 (40°C)	%
Hydrogen sulphide	0-4000	ppm

Operational parameters

The AD process is very dependent on how quickly the bacteria proliferate. In order to improve microbial activity and hence the AD efficiency, the operational parameters of the digester are therefore regulated. Below is a description of the most crucial parameters.

Temperature

While practically all climatic circumstances make AD technology generally possible, the digestion process is not successful at low temperatures (mean temperature below 15°C) (Vögeli et al, 2014). In order to extend the retention period in cool climates, either a heating system must be installed or a larger digester must be constructed. However, the required additional investment expenditures and fuel requirements for heating may make the biogas system commercially unviable. Heating systems and insulation can provide ideal digestion temperatures even in cold climates or seasons.

pH

According to Khalid et al , (2011), the ideal pH range for an AD process that is generally stable and produces a high amount of biogas is between 6.5 and 7.5. In contrast to the methanogenic phase, which takes place at acidic pH levels (pH 6.5–8.1), the processes of hydrolysis and acidogenesis occur during digestion at acidic pH levels (pH 5.5–6.5). To maintain a suitable buffering capacity, a level of alkalinity of roughly 3 000 mg/L must be present at all times. Lime is frequently used to increase the pH of AD systems when the process is overly acidic.

Organic Loading Rate

The biological conversion capability of the AD system is gauged by the organic loading rate (OLR). It reflects the volume of substrate that was added to the reactor at a specific moment (see Table 3). Since overloading causes a considerable increase in volatile fatty acids, which can cause acidification and system failure as previously mentioned, OLR is a particularly crucial control parameter in continuous systems. Studies on the anaerobic treatment of biowaste in developed nations describe organic loading rates of 4 to 8 kg VS/m^3 reactor and day, which lead to VS elimination in the range of 50 to 70% (Vandevivere et. al, 2003). This is perfect for reactors that are continuously stirred.

Hydraulic Retention Time

The amount of time the liquid fraction spends inside the reactor is measured by the hydraulic retention time (HRT). It is determined by dividing the reactor's (active slurry) volume by the feedstock input flow rate (see Table 3). The HRT necessary to enable complete AD reactions varies depending on the technology used, the process temperature, and the type of waste. HRTs of 10 to 40 days are advised for wastes processed in a mesophilic digester. In digesters operated in the thermophilic range, shorter retention times a few days at most are needed (Verma, 2002). Although there is a difference between hydraulic retention time (HRT) and solids retention time (SRT), HRT and SRT are typically regarded as identical for the digestion of solid waste.

Table 3: Main parameters for evaluation and comparison of different AD system performances (Mata, 2003)

Operational Parameter	Formula	Desciption	Unit
Hydraulic Retention Time (HRT)	HRT=V/Q	HRT: Hydraulic Retention Time V: Reactor volume Q: Flow rate	Days m^3 m^3/day
Organic Loading Rate (OLR)	OLR=Q*S/V	OLR: Organic loading rate Q: Substrate flow rate S: Substrate concentration in the inflow V: Reactor volume	kg substrate (VS)/m^3 reactor and day m^3/day kg VS/m^3 m^3
Gas Production Rate (GPR)	GPR=Qbiogas /V	GPR: Gas production rate Qbiogas: Biogas flow rate V: Reactor volume	m^3 biogas/m^3 reactor and day $m^{3/}$day m^3
Specific Gas Production (SGP)	Qbiogas/Q*Sor GRP/OLR	SPG: Specific gas production Qbiogas: Biogas flow rate Q: Inlet flow rate S: Substrate concentration in the inflow	m3 biogas/kg VS fed material m3/day m3/day kg VS/m3

Results

The preliminary survey showed that the campus generates an average of 60 kg/day of bio-waste (wet weight). In a mixture of one-part trash to two parts water, this raw feedstock will be diluted. This will produce a slurry that is simple to discharge into the digester. As a result, 180 L of diluted feedstock are consumed every day. (i.e. 1*60+2*60, using the approximation that 1 kg is equivalent to 1 litre).

Hydraulic Retention Time (HRT)

The ideal HRT for a tropical climate with an average ambient temperature of 25–30°C

is recommended to be around 30 days, which means that an active reactor volume of

5.40 m^3 is required (i.e. 180 L/day*30 days = 5400 L).

Feedstock characteristics and Organic Loading Rate (OLR)

The total solids (TS) content of the available bio-waste, which is a mixture of vegetable, fruit, and food waste, is 20%. In other words, 20%, or 12 kg, of the 60 kg wet weight is made up of dry stuff. With a dry matter concentration of 80% volatile solids (VS), there are 9.6 kg of volatile solids and 2.4 kg of non-volatile solids. Water, which doesn't include volatile solids, makes up the remainder of the bio-waste. As a result, 9.6 kg of the 180 L of diluted feedstock's volatile solids content. Calculated to 1 000 litres (i.e. 1 m^3) of diluted feedstock this is equivalent to 53.3 kg VS/m^3 inflow (4 * 1 000/180).

The Organic Loading Rate (OLR) can then be calculated as follows (see Table 3): OLR=Q*S/ V

Whereby Q is the substrate flow rate (m^3 /day), S is the substrate concentration in the inflow (kg VS/m^3) and V is the reactor volume.

Therefore: OLR =0.18 (m^3/day) * 53.3 (kg VS/m^3) /5.4 (m^3) =1.78 kg VS per m^3 reactor volume and day.

An OLR below 2 kg VS/m^3 reactor volume and day is considered ideal for non-stirred AD systems.

Size of the AD system

A fixed-dome digester is designed so that 75% of the total reactor volume is used for the active slurry and 25% of the volume is used for gas storage. In this example, this means that the active volume of 5.4 m^3 (equals 75% of total) is complemented with 1.8 m^3 gas storage volume (25%), resulting in a total digester volume of 7.2 m^3 for the whole reactor. The identified site is a square shaped with the length of 6.75 m giving the area of; A= 45.6 m^2. The proposed dimensions of the appropriate tank for this process are 1000 L 38 kg and the tank is found in Agra and Build-it stores in Namibia. It costs approximately N$ 2000.00. If the other costs related to piping, maintaining and building are included, the total cost can be estimated at N$ 15.000.00. Given that food waste typically yield biogas volumes of 0.67 m^3 per kg VS (assuming 0.4 m^3 CH_4/kg VS and methane content of 60%, see Table 4), it is reasonable to assume that 6.4 m^3 of biogas is produced daily (1.78 kg VS/m^3 reactor and day*0.67 m^3 biogas yield per kg VS*5.4 m^3 reactor volume, equals to 6.4 m^3/day). The flow rate of biogas is Q_{biogas}. With a biogas composition of 60% methane (CH_4), this results in a daily methane production of 3.84 $m^{3.}$ The Gas Production Rate (GPR) can be calculated as follows (see Table 3):

GPR = Q_{biogas} / V

Therefore: GPR =6.4 m^3 /d /5.4 m^3 =1.185 m^3 biogas /m^3 reactor and day

The Specific Gas Production (SGP) can be calculated as follows (see Table 3):

SGP = GRP/OLR Therefore: SGP = (1.185 m^3 biogas/m^3 reactor and day)/(1.78 kg substrate/m^3 reactor and day) = 0.67 m^3 biogas /kg VS fed material.

Electricity demand and cost

The major determining factors for electricity demand are the population of the campus and the purpose of its usage. Usually, it is challenging to estimate the electricity demand in universities since people are involved in diverse activities. The electricity demand data for each month has been obtained from the finance office. The average monthly consumption is approximately 242.20 KVA.

The typical biogas cooking stove uses 0.4 m^3 of biogas every hour (Sathr et.al, 2020). Therefore, a biogas cooking stove can run for 16 hours (or 4 hours of cooking on four stoves) using the 6.4 m^3 biogas generated in this case. Given that 1 m^3 of biogas includes 6 kWh of energy, the daily production of biogas in this example (6.4 m^3/24 hours) comprises 38.4 kWh. Thus, the power is 1.6 kW (38.4 kWh/24 hours).

The total power that can be produced monthly will be 1.6 × 31=49.6 KVA.

Conclusion

We have analysed different types of biogas digesters. Various factors that enable the production of biogas were critically reviewed. The Portable biogas digester is found to be the appropriate model to be used on campus and it is easily found in local shops. The establishment of such system will help to reduce the consumption of electricity as the use of biogas cooking stoves will allow to save every month 49.KVA. The avoided Green House Gas (GHG)-emission is around 64 GgCO2-eq per year when using food waste to produce biogas instead of landfilling the waste. The results also demonstrate that an effective partnership between research and community involvement can produce knowledge and abilities that can be conveyed to aid a community in embracing biogas as a renewable energy source. Additionally, we advise government should help spread the use of biogas technology as a clean energy source in rural areas. This would support spreading knowledge about the technology and increase usage of it. Rural residents will also be made aware of the useful benefits of this technology through the construction of prototype digesters in those communities, enabling them to benefit from it.

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