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Research Article

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Biogas a Sustainable Source of Clean Energy in Sub Saharan Africa: Challenges and Opportunities

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Abstract
Energy security, socio-economic growth and environmental protection are the national energy policy drivers of any country of the world today. The World Energy Forum has predicted that fossil-based oil, coal, and gas reserves is on the decline due to increase in energy demand. Despite advancements in modern technology, a larger population living in the rural areas in sub-Saharan countries use biomass in their traditional means for domestic cooking, heating and lighting. However, this rises severe environmental and health issues. An alternative source of renewable energy with abundant availability of biomass in sub- Saharan Africa will be biogas. Biogas is a sustainable and affordable renewable energy fuel and is environmentally safe in reducing greenhouse gases (GHGs) during combustion. However, there exist many challenges in biogas production and utilization, which includes high operation costs, high energy consuming processes, lack of sufficient government policy, and public - private partnership support. In addition, a concerted effort from all stakeholders are essential to facilitate the installation of small and medium biodigesters to harness the inherent potential that is currently not utilised. This review highlights the relevance of biogas technology in tune with the Sustainable Development Goals (SDGs) laid by the United Nations to make biogas a futuristic bioenergy for the well-being and prosperity of people living in sub-Saharan countries.

Keywords: Biogas, Anaerobic, Biomass, Renewable, Sustainable.

Introduction
Energy is an indispensable part of our daily life. Millions of households and communities around the world have no access to basic energy services. It is estimated that 45% of global population live on solid fuels such as firewood, cattle dung, agricultural residues, and coal to meet their energy demands. International treaties like Agenda 21 and Kyoto Protocol are advocating developing and utilizing renewable energy sources in the wake of depleting conventional fuels [1, 2]. In view of this, the researchers all over the world have engaged in the development of alternative energy sources to solve the energy demands. Coal has remained the main reliable source of energy in the 19th century. The energy usage was growing rapidly due to the high increase in world population. Then it is directed towards oil consumption. Since the oil fuel is facing severe environmental problems, now the world is directed to use natural gas, which has 75-98% methane this shifting of energy resources from one form to another is shown in Figure 1.

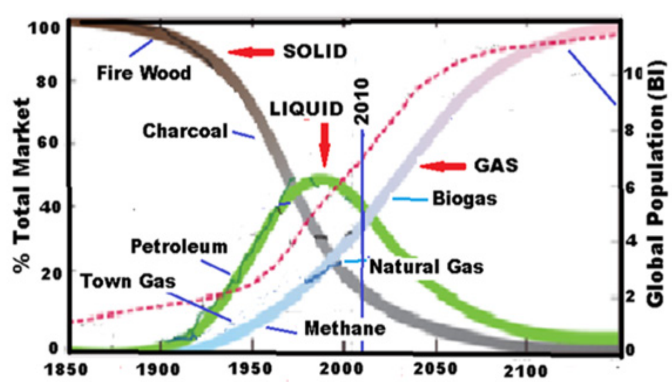

Figure1: Transition of Global energy system (modified from Ref.3).

Nowadays, gaseous fuels such as natural gas and biogas have become the first choice for generating heating power and electricity. They are clean fuels, which on combustion emit little or no pollutants that are harmful to health and the environment. A detailed investigation shows that the gaseous fuel has a low carbon content, clean and environmentally friendly. A comparison of various renewable source of fuels are shown in Table 1.

Table 1: Comparison of various renewable source of fuels (Ref.26).

No	Types of Fuel	Equivalent of BG ($1m^3$)	Energy Value 10^3x (kCal/Kg)	Useful heat kCal/Kg	Thermal Efficiency (%)
1	Coal gas ($1m^3$)	1.177 (m^3)	4.004	2400	60
2	Char coal (1 Kg)	1.458 (Kg)	6.930	2079	28
3	Cow dung (1 Kg)	12.29 (Kg)	2.090	209	10
4	Firewood (1 Kg)	3.474 (Kg)	4.700	470	10
5	Gobar gas (1 m^3)	-	4.713	2700	60
6	Kerosene (1Lt)	0.62 (Lt)	9.600	4800	50

In recent years, sub-Saharan Africa (SSA) has been experiencing a lack of access to energy. In sub-Saharan Africa, some 609 million people have no access to electricity. Moreover, close to 800 million people rely on traditional biomass fuels [4]. This causes negative socio-economic, health, and environmental impacts. In this context, enhancing a clean sustainable renewable energy would be the real-time solution. The recycling of the waste materials to useful energy sources through waste-to-energy technologies has been reviewed [5].

African's waste management is still in its infancy stage. Only 4% of the continent's waste is being recycled. In most of the SSA countries, the municipal solid waste (MSW), mostly consists of organic matter, posing a serious threat to environmental and ecological damages such as soil erosion, surface and groundwater pollution. Municipal solid wastes (MSW) such as kitchen waste, cattle dung, crop residues and green wastes are available in plenty to produce sustainable clean renewable energy through anaerobic digestion (AD). This could certainly improve the quality of human health, the local environmental and the socio-economic conditions.

Anaerobic digestion is a biological process that converts organic waste into energy-rich biogas in the absence of oxygen. It is used as a clean renewable energy source for domestic cooking, heating, lighting, and as a transportation fuel. The bio-digestate, a nutrient-rich residue obtained after digestion is used as a soil conditioner and/or organic fertiliser to increase agricultural productivity [6]. Thus, AD can enhance the energy demands of SSA countries to a large extent. This review deals with the current situation of biogas in SSA countries and the application of anaerobic digestion to produce biogas in meeting the energy demands within SSA region. This will significantly reduce energy poverty and promote environment safety [3].

Literature Review

Biogas research is being conducted all over the world and many research papers have been published since 1990 (Figure 2). Major contribution on this research has come from technologically advanced countries. Most of the publications on biogas are research articles (73%) followed by conference papers (11%) and Review articles (10%) [7].

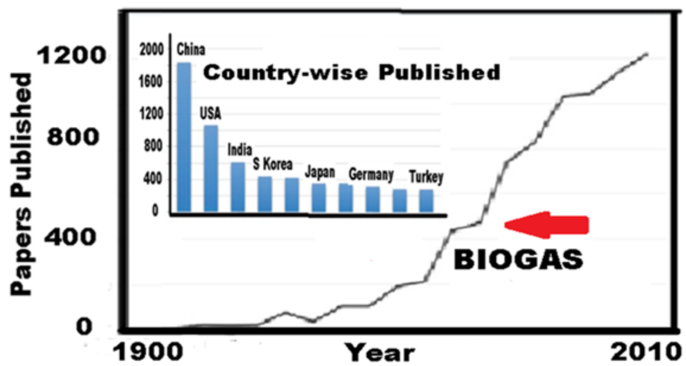

Figure2L: Research papers published on biogas.

Sub-Saharan Africa is endowed with abundant renewable energy resources that are yet to be exploited. Biogas technology is one such appropriate technology, which is highly suitable to improve upon the energy security within the region. Several sub-Saharan countries have successfully installed biodigesters to produce biogas from various renewable waste resources [8].

Ethiopia has installed the Reppie thermal plant to convert the waste resources to biogas production. The plant thus provides electricity to the tune of 30%. In Nigeria, the urban poor and the rural households still depend on biomass for their energy needs. The identified feedstock substrate includes wastes from water sources, industry, agricultural residues, and municipal sewage [9-11]. It has been reported that Nigeria produces about 6.8 million m3 of biogas every day. Even other renewable resources coming from poultry farms have been critically assessed for their possible use in biogas production [12]. This suggests that biogas production in Nigeria may be a useful means of reducing the urban wastes into energy [9].

Sudan is an agricultural country with plenty of water resources, livestock, forestry, and agricultural residues. There are 200 installed biogas units to cater for family, community, and few industrial houses. The main substrate comes from agricultural residues and animal wastes. There have been some efforts to produce biogas from water resources such as water hyacinth, since it is abundantly available on the basin of White Nile [13, 14].

Tanzania is a tropical country has plenty of biomass resources, which are sustainable to produce biogas. This includes municipal solid waste (MSW) and agro-industrial wastes [15-20]. During early 70s, the government installed few floating gasholder digesters. In mid 90s, the first simple low-cost polyethylene tubular biodigesters were introduced in the country using local materials and simple installation procedure [21].

Zimbabwe's economy is based on agriculture. Therefore, large quantities of biomass residues from agricultural activities, industrial residues and municipal solid wastes are available to generate biogas. Total biomass energy theoretically available in Zimbabwe has been estimated to be 48.5% from agriculture, 29.8% from forestry and 21.7 % from livestock [22].

Congo has plans to set aside part of its arable land for biogas production. Cassava is grown in most parts of the Congo with a total production of 861,500 tons and during the processing of cassava roots, large quantities of solid wastes (cassava peel) are produced. The cassava peels could be used to produce a significant quantity of biogas [23, 24].

Like other countries in southern Africa, Botswana too depends on bioenergy. Currently renewable energy contributes only around 1% to total energy consumption and it comes mainly from solar energy. As is the case with most other African countries, enhanced research capacity is underway to develop biogas production from animal dung, municipal solid waste, and industrial waste [25].

The literature available on biogas technology in other sub Saharan countries was found to be minimal. However, the potential for biogas production is huge in most of these countries. This is due to the availability of abundant quantities of biomass wastes generated from agriculture, industries, municipality, wastewater, and forestry.

Biogas Technology

Biogas is a futuristic renewable energy source required for both urban and rural activities. It has a high market potential due to the wide availability of organic biomass. It comprises mainly CH4 (55-65%), CO2 (35-45%), a trace quantity of H2S (<1.0%) and water vapor. The average calorific value of biogas is 20 MJ/m3 (4713 kcal/m3). Biogas cannot be easily liquefied under normal temperature and pressure. The critical temperature required for liquefaction of CH4 is minus 82.1oC at 4.71MPa pressure. The heat value of this gas amounts to 1.3 x 1012 MJ.

Though, biogas has about 60% as compared to natural gas (CH4 = 75 to 98%), it is possible to
enrich the CH4 content of the biogas closer to that of natural gas [26-30]. An enriched biogas after compression can be used as transportation fuel like compressed natural gas (CNG). It has lower emission level than natural gas and diesel. A comparison of gaseous emissions between natural gas and biogas is shown in Table 2.

Table 2: A comparison of emissions level between natural gas and biogas

No.	Fuel (g/Km)	CO	HC	NOx	CO2	Particulates
1	Natural gas	0.40	0.60	1.10	524	0.022
2	Biogas	0.08	0.35	5.44	233	0.015

Biogas is a promising renewable energy produced by anaerobic digestion (AD) of Feedstocks, in the absence of oxygen. Anaerobic digestion consists of several interdependent, sequential, and parallel biological reactions. The conversion of organic matter into biogas is carried out by a consortium of microorganisms through a series of metabolic stages, namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis (Figure 3). During the reaction, the products formed from one group of microorganisms serve as the substrates for the subsequent reaction. The transformation of biomass finally leads to the formation CH4 and CO_2.

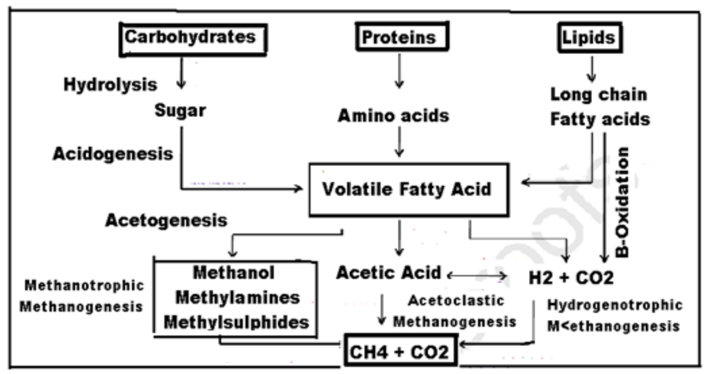

Figure3: Major Stages of biogas production (modified from Ref.6).

Methanogenesis step which is carried out by a specialized microbial group of archaea is highly sensitive to variations in temperature, pH, C/N ratio and maintaining the optimum conditions for the AD process is a key for enhancing biogas yield [31]. A common problem usually encountered in biogas production is low biogas yield due to the use of single feedstock, which may be either recalcitrant to digestion or have a low or high C/N ratio.

Moreover, most of the studies involving single-stage AD have reported low CH4 content in biogas. These limitations can be resolved by co-digesting diverse feedstocks and optimizing the C/N ratio, total solids content (TS) and volatile solids (VS) content. This also helps in reducing ammonia production during AD, thus reducing the chances of inhibition caused by ammonia. This also increases the digestibility of the feedstock, thereby enhancing the production of biogas [32]. In the net reaction, for high solids feedstocks, hydrolysis is the rate-limiting step while for highly soluble feedstocks, methanogenesis is the rate-limiting step. The composition of biogas and the amount produced varies with the type of feedstock as shown in Table 3. The operating condition of the digester. CH4 is the only component of biogas that contributes to the heating value.

Table 3: Shows the methane content present in various renewable source of fuels.

No	Feed /Substrate	BG production Lt/Kg	Methane %
1	Cattle dung	40.0	60.0
2	Crop residues	100.0	65.0
3	Bagasse	33.0	56.9
4	Fruit waste	91.0	49.2
5	Food waste	160.0	62.0
6	Non-edible oil residue	242.0	67.5

Benefits of Biogas

Biogas being a clean source of energy, it can be used in diverse purposes (Figure 4). it is built on a circular economy Biogas generated is non-polluting and significantly reduces the greenhouse emissions. Hence, using biogas generated from waste resources as a form of energy is meaningful way to combat global warming. Biogas does not require any energy during the anaerobic digestion process. The resources required to produce biogas are renewable, such as agricultural residue, cattle manure, food scraps and municipal waste, which will always be available, this aspect of biogas makes a highly sustainable.

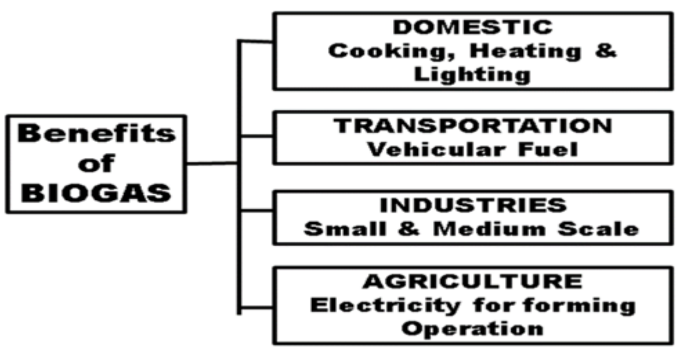

Figure 4: Benefits of Biogas in various sectors.

In the domestic sector, biogas technology is simple and low-cost. It is easy to set up a small-scale biodigester with little investment. A household biodigester can be easily installed right at home using kitchen waste and animal manure. A household system can recover the installation cost after a while since the feedstock used for biogas generation is free. This allows the cost of biogas production to be relatively low. The biogas produced can be used directly for domestic cooking, heating, and lighting. In the transportation sector, biogas can be used as vehicular fuel after its enrichment (i.e. removing CO2, H2S and water vapour present in it). The enriched biogas is compressed up to 20 MPa pressure using a three-stage compressor and filled in special high-pressure steel cylinders (as used in CNG filling). Biogas enrichment and compression system is suitable for a large-scale biogas as there will be sufficient biogas available for bottling and making it more economical. The technology ensures sustainable development and energy security with employment generation in rural areas using cattle dung and biomass [25]. In the industrial sector, it reduces soil and water pollution. Industrial solid waste thrown in landfills and toxic effluents discharged in the drain can be minimized in producing biogas. This indirectly improves the quality of ground water. Moreover, anaerobic digestion deactivates pathogens and parasites and thereby the incidence of waterborne diseases decreases drastically. Similarly, waste collection,

Sustainability of Biogas

The sustainability of biogas is driven by its production rate and purity, to get biogas at an affordable cost. The use of biological methods for biogas production operate in mild conditions and has lower energy demands, which make the process cost-effective. However, there are some challenges that need the attentions of researchers and industrialists for biogas production, such as utilisation of organic residues, maintenance of biodigesters and enrichment technology in an environmentally acceptable form [25].

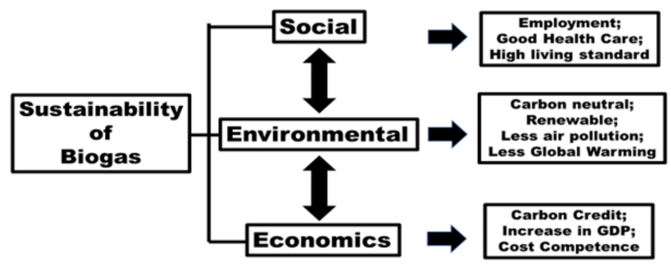

Figure 5: Aspects of biogas as a sustainable fuel.

The three criteria for sustainability are economics, environmental performance and social issues (Figure 5). It mainly refers to simultaneously achieving economic prosperity, environmental cleanness, and social parity [33]. These three aspects are measured by feasibility assessments, evaluation of biofuels sustainability, life cycle and techno-economic analysis [34].

Challenges of Biogas

Despite its significant economic, environmental, and social merits, biogas technology has not permeated much into the energy demands of developing countries. Some of the reasons may be as follows:

At times even after refinement and compression, the enriched biogas may still contain small trace of impurities. If it is used as a vehicle fuel, it can corrode the metal parts of the engine. This corrosion would lead to increased maintenance costs. However, the gaseous mix is more suitable for kitchen stoves, water boilers, and lamps. The biogas generation can be affected by the weather. The optimal temperature bacteria need to digest waste is around 37°C. However, in cold climates, biodigesters will require external heat energy to maintain the optimum temperature to generate biogas and for a constant supply. At times large size biodigesters have the disadvantage in being installed in large urban areas. It needs large quantities of renewable raw materials to generate enough biogas. This may be the reason to recommend biogas generation to be more suitable for rural and suburban areas. Lack of technical knowledge and construction skills in building biogas plants and their maintenance as well, is another constraint in not having adequate numbers of installations in most of the SSA countries. Although energy poverty is critical in most of the sub-Saharan countries, the consideration as well as the implementation energy have not received enough attention from the government policy makers nor with private-public participatory bodies. Most of the engineering and technical courses offered at various levels in the SSA region; do not teach courses pertinent to the effective harness of biogas technology in depth. The lack of education and awareness in not knowing the importance of using biogas technology by the rural population living in the sub-Saharan countries, lead them with severe health issues in using renewable biomass such as firewood, cattle dung cakes, crop residues directly for their domestic consumption. Water is essential for both the installation and operation of biogas plants. The scarcity of water in most of the land locked countries within SSA region hinders the widespread adoption of biogas technology. Public awareness and general education further impede the progress of biogas technology in most of the developing countries within SSA region. To make the biogas technology more transparent and viable, the public must be sensitised on the potential economic, health, social and environmental merits through a variety of mass media and advertisement of biogas programme with stakeholder.

Conclusion

The present article has reviewed the status of biogas technology as a source of renewable and sustainable source of energy as well as a clean economical fuel in comparison to other biofuels in sub-Saharan countries. In sub-Saharan Africa, a large population living in rural areas relies heavily on traditional biomass resources to meet their daily energy needs. In a long run, this causes a severe health and environmental damages. To surmount this problem, a sustainable and affordable energy in the form of biogas is required in most of the countries within SSA. Installation of biodigesters is a simple and cost-effective technology to implement to produce biogas. Implementation of biogas technology, both in medium and large scale with the availability of different kinds of feedstock provides clean energy. Reduces environmental and ecological damages and opens up more job opportunities. Development of biogas economy is a feasible alternative for sustainable fuel as it provides energy security, societal parity and environmental safety.

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