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Medium-Scale Biogas Plants: Feasible solution for the management of organic waste in Nigeria

BACHELORS THESIS

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Declaration

I hereby declare that I have done this thesis entitled "**Medium-Scale Biogas Plants: Feasible solution for the management of organic waste in Nigeria**" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 17/04/2024

Monsur Akin Abisoye Liasu

………...................................

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Abstract

Biogas plants are a big initiative for the management of waste production in Nigeria and a one-stop solution to the growing organic waste problem. This study explores the potential of medium-scale biogas plants for the processing of organic waste materials from organic wastes and their benefits to the community. On the basis of this research, the idea of the policies employed by the government, the cost-effective production of biogas from organic wastes, conversion of biogas for generation of electricity, and the working of a biogas plant along with its design, has been highlighted and shows the importance of employment of a medium-scale biogas plant. Therefore, this research discusses the problems, challenges, and limitations faced by Nigeria in the adoption, use, and development of medium-scale biogas plants as a feasible solution for the management of organic waste in Nigeria and provides working recommendations on how this technology will be used as a sustainable technology for the betterment of the lives of the people and economy of the country.

Keywords: Biofuel, Biogas, Biomass, Organic waste, Renewable energy

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List of the abbreviations used in the thesis

AFW-Amount of Food Waste

BY-Biogas Yield

CEGR-Captive Energy Generation Regulations

GWh-GigaWatt-hour

IRENA- International Renewable Energy Agency

Kg-Kilogram

kWh-kiloWatt-hour

MJ-Megajoules

MSW-Municipal Solid Waste

NEEAP-National Energy Efficiency Action Plans

NEP-National Energy Policy

NEPIP- National Electric Power Implementation Policy

NERC- Nigerian Electricity Regulatory Commission

NREEEP- Nigerian Renewable Energy and Energy Efficiency Policy

PJ-Picojoules

REMP-Renewable Energy Master Plan

REPG-Renewable Energy Policy Guidelines

SDG-Sustainable Development Goal

TBO-Total Biogas Obtainable

UNGA-United Nations General Assembly

VS-Volatile Solids

WHO-World Health Organization

1. Introduction

Biogas is a crude form of natural gas; it is a type of biofuel naturally produced from the decomposition of organic matter (plant and animal products) by bacteria in an anaerobic (oxygen-free) environment. It consists mainly of methane and carbon dioxide [1]. Jan Baptita, Van Helmont in the 17th century first discovered that flammable gases could evolve from decaying organic matter. Count Alessandro Volta in 1776 concluded that there was a direct relationship between the amount of decaying organic matter and the amount of flammable gas produced [2]. However, Sir Humphry Davy in 1808 discovered that the anaerobic digestion of mature cattle contained methane along with other gases produced [3]. In 1859, the first biogas digestion plant was built in India at Leper Colony, Bombay, and in the 1950s the development of small biogas plants was started for use in rural households [3]. In China, prosperous families began to build biogas plants in the 1940s; however, biogas technology developed rapidly in the 1970s with much assistance from the Chinese government. In 2007, China was recorded as the world's largest biogas producer with about 3,500 medium to large-scale digester units and approximately 18 million farm households using biogas [3].

Lack of access to adequate energy resources, inadequate energy supply, and environmental pollution caused by solid and liquid waste are some of the major problems facing Sub-Saharan African countries [4]. Less than 10 % of the 21 Sub-Saharan African countries have access to energy; therefore, there is a serious need to develop alternative and renewable energy sources from locally sourced materials and locally available resources in pursuit of national development and generation of energy for human survival in the region. Furthermore, it is necessary to adopt relevant and economically feasible technologies to solve the problems associated with the management of solid and liquid waste in the region and the energy recovery from them. Developing countries such as Nigeria are heavily dependent on fossil fuels for energy generation. The Sub-Saharan African region including Nigeria has enormous conventional energy resources- coal, crude oil, tar sands and natural gas- in addition to the large amount of sustainable and renewable energy resources, including solar, hydro, wind and biomass. However, these alternative energy sources require massive economic investment and technical power to operate, which makes them a little more challenging for these countries [4].

Biogas energy is a reliable and economically feasible source of alternative and renewable energy generated from organic waste materials through the application of simple technology. The prospects of biogas technology are bright because it provides an effective solution for the management of organic waste and can also be used to provide energy for households, farms, industries, and rural communities [5]. The development of small-medium-scale biogas plants is still in its infancy in Nigeria due to factors such as planning and construction errors, misconceptions of the benefits of technology, inadequate maintenance culture, and the lack of significant effort directed at evaluating the composition of anaerobes responsible for the decomposition of organic waste [4].

Nigeria's urban population in 2030 is estimated to be between 46 and 54% of the total population, which is also estimated to be approximately 250 million. This is an indication that a large population of the population will still live in rural areas. Already, the country is facing an energy crisis – both commercial and traditional energy resources. Petroleum products have been in acute shortage in urban areas since the early 1990s, although less acute incidents have been observed since 1975. In Nigeria, the feedstock substrate identified for an economically feasible biogas programme includes water lettuce, water hyacinth, dung, cassava leaves, urban refuse, solid waste (including industrial) waste, agricultural residues and sewage [6]. Nigeria has been estimated to produce about 227,500 tons of fresh animal waste per day. Nigeria can produce approximately 6.8 million m^3 of biogas per day, as 1 kg of fresh animal waste produces approximately 0.03 m^3 of gas. In addition to all of these, 20 kg of municipal solid waste (MSW) per capita has been estimated to be generated in the country annually [7]. Therefore, biogas production may be a profitable means of reducing or even eliminating the menace and nuisance of urban waste in many cities by recycling them. To contain the uncertainty usually associated with the typical structural transformation of the economy of a developing country such as Nigeria, a three-scenario analysis has been adopted to examine the future prospects of biogas in the country. Although the energy generated from biogas would range between $5.0\text{-}17.1 \times 10^{12}$ J in the period 2000-2030 under a moderately ambitious biogas technology programme, some constraints may hinder this realisation. These include economic, technical, and socio-cultural constraints [6]. Biogas technology is considered by many experts an excellent tool to improve life, livelihoods, and health in the developing world, which converts biological waste into energy. Small-scale biogas technology is being used by about 16 million households worldwide, according to *Renewables 2005: Global Status Report*, a study by the Worldwatch Institute. The Ibadan plant will be one of the largest biogas installations in Africa, providing gas to 5,400 families a month at around a quarter of the cost of liquefied natural gas. The Ibadan digester will take advantage of the city's municipal abattoir in Bodija, where almost two-thirds of the animals in the Oyo state are slaughtered, according to a study in the African *Journal of Environmental Assessment and Management in January 2002*. The waste from the slaughtering houses are rinsed into open drains that connect to surface water; and also seeps into groundwater. About 60% of Ibadanians get water from hand-drained wells vulnerable to contamination and about 15% have private wells, according to Tijani Moshood, a geologist at the University of Ibadan. Joseph Adelegan, a civil engineer and project director for Cows-to-Kilowatts, estimates the project to cost around US$300,000. Start-up funds have been obtained, and construction of the new plant is expected to begin in July 2006 [8]. The biogas potential in Nigeria is estimated to be approximately 6.8 million m^3 per day from animal manure and 913,440 tonnes of methane from MSW, equivalent to 482 MW of electricity. Furthermore, it has also been estimated that up to 171 TJ of energy could be generated from biogas by 2030 in Nigeria [9]. Therefore, this research will be carried out to discuss the problems, challenges and limitations faced by Nigeria in the adoption, use, and development of medium-scale biogas plants as a feasible solution for the management of solid and liquid waste in Nigeria and to provide working recommendations on how this technology will be sustained in the country.

2. Literature Review

2.1 Biogas technology (production and use) and background and history:

Biogas is a naturally occurring gas that is generated by the breakdown of organic matter by anaerobic bacteria and is used for the production of energy. The process involved is known as anaerobic digestion, which is a biochemical process of decomposition of organic compounds by microbes under anaerobic conditions. The process is similar to some natural processes like peat formation, or the process in the ruminant digestive system. Methane fermentation requires associations of diverse bacteria, which are aceticlastic and hydrogenotrophic methanogens, syntrophic acetogens, fermentative bacteria, and homoacetogen [10, 11]. It differs from natural gas in that it is a renewable energy source produced biologically unlike fossil fuels produced by geological processes. Biogas is mainly composed of methane gas (CH_4, up to 75%) and carbon dioxide (CO_2, up to 50%), and hydrogen (H_2), nitrogen (N_2), water vapour ($H_20)_{(g)}$, and hydrogen sulphide (H_2S) are present in trace amounts. Along with these substances traces of iron, cobalt, nickel, selenium, molybdenum, and tungsten can also be present [12]. The use of biogas for the very first time dates back to the Assyrian empire about 3000 BC. Biogas obtained by decomposing organic matter was initially used to heat water. Later in the 17th century, it was determined that flammable gases could evolve from decaying organic matter. Count Alessandro Volta also concluded that there was a direct correlation between the amount of flammable gas produced and the amount of decaying matter. In 1808, it was also found that methane was present in the gases produced during the anaerobic digestion of cattle manure. The first modern digestion plant was recorded in India in the 19th century [13]. The composition of biogas and its properties depend on the type of substrate or biomass entering the process, the type of facility, and the conditions of the process. Table 1 below compares the composition of raw biogas and natural gas, where individual volume shares differ less depending on the source of the literature.

Table 1: Biogas vs. natural gas composition [14,15,16,17].

Compound	**Formula**	**Volume Share (%)**			
		Biogas			**Natural Gas**
		Korbag et al. [16]	**Persson et al. [14]**	**Moya et al. [17]**	**IEA Bioenergy [15]**
Methane	CH_4	50-75	53-70	55-70	83-98
Carbon dioxide	CO_2	25-50	30-47	30-45	0-1.4
Water	H_2O	5-10	-	0-5	-
Oxygen	O_2	<2	0	0-3	-
Nitrogen	N_2	<10	0.2	<15	0.6-2.7
Ammonia	NH_3	<1	<1	<1	-
Hydrogen	H_2	<1	0	-	-
Hydrogen Sulfide	H_2S	<3	<1	<1	-
Ethane	-				<11 %
Propane	-				<3 %

Biogas production can be achieved by two fermentation processes. In the dry process, the solid concentration in the fermenter is less than 10%, and in the wet process, it ranges from 15 to 35% [10, 18]. The factors that affect this process are temperature, substrate particle size, carbon-to-nitrogen ratio (C/N), and pH value. The process operates in the pH range from 5.5 to 8.5 and optimally at higher values, and smaller particles undergo faster decomposition, resulting in faster biogas generation. According to Sahota et al. [19], the optimal C/N ratio is in the range of 20/1 to 30/1 [20, 21]. The environment for the process used can be divided into psychrophilic (low temperature), mesophilic (moderate temperature) and thermophilic (warm). The psychrophilic process operates at a temperature below 30°C, the mesophilic occurs at a range of 30 to 42°C and the thermophilic operates at a range of 43 to 55°C. Too low or too high temperatures are not suitable as they may slow down the process [21]. Mesophilic and thermophilic are most commonly used and the temperature is maintained by installed heat exchangers. The advantage of thermophilic biogas production is that they offer a higher rate of methanogenic bacteria, shorter digestion time, higher efficiency, and better substrate utilisation. It occurs naturally in compost heaps as swamp gas and in cattle and other ruminants as a result of enteric fermentation, it can also be produced in anaerobic digesters from plant or animal waste or can be collected from landfills. The continued use of fossil fuels, which are limited in nature and also due to their presence in politically unstable regions, and the harmful effects of greenhouse gases on the environment have led researchers to look for other means which are more environmentally friendly and easily accessible. In this context, waste and residue biogas can play a crucial role in the future as an alternative energy source. The by-product of anaerobic digestion technology, called digestate, is a high-value fertiliser for crop cultivation and as a replacement for common mineral fertilisers. The use of biogas is a green technology with no harmful effects on the environment. It is burnt to generate heat or can be used in combustion engines to produce electricity. Biogas technology effectively uses accumulated animal waste from food production and municipal solid waste from urban areas. The conversion of organic waste to biogas reduces the production of methane, which is a greenhouse gas, and efficient combustion replaces methane with carbon dioxide, which is safe for the environment. The wastes are processed in anaerobic digesters as liquid or slurry mixed with water. Digesters are generally made up of a feedstock source holder, a digestion tank, a biogas recovery unit and heat exchangers to maintain the temperature necessary for bacterial digestion. Small-scale household digesters with 757 liters can be used to provide cooking fuel or electricity in rural homes. The primary types of farm digesters used are complete mix digesters for slurry manure, covered lagoon digesters, plug-flow digesters mainly for dairy manure, and dry digesters generally for slurry manure and crop residues. Heat is required in digesters to maintain a constant temperature of 35°C for bacterial decomposition of organic matter into gas, and can produce 200-400 m^3 of biogas containing 50-75 percent methane per dry ton of input waste. The organic matter and its natural decomposition occurs over many years and the biogas produced can be collected from a series of interconnected pipes located at various depths in a landfill. The composition of this gas changes over the life of the landfill where after one year the gas is generally composed of 60% methane and 40% carbon dioxide. Landfill collection also varies according to the percentage of organic waste and the age of the facility wan with an average energy potential of about 2 gigajoules per ton of waste. The chemical composition and biodegradability of the used substrates affect biogas composition [22]. The substrates rich in lipids and proteins yield high amount of methane compared to those rich in carbohydrates, but high lipid content leads to the failure of the anaerobic digestive system due to the generation of long-chain fatty acids. On the other hand, carbohydrates rich substrates can negatively affect the C/N ratio, resulting in restriction of nutrients and rapid acidification [23]. Figure 1 shows a general flow chart of the anaerobic digestion process. The conversion of biomass to methane follows four different microbial processes, which are hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Hydrolysis involves decomposition in the presence of water, and the longer-chain chain carbohydrates are broken down into shorter chains (monomers). Acidogenesis involves the conversion of monomers into fatty acids. Acetogenesis involves the uptake of fatty acids and their conversion into acetic acid, along with carbon dioxide and hydrogen. Finally, in methanogenesis, acetic acid and hydrogen are consumed, releasing methane and carbon dioxide as final products.

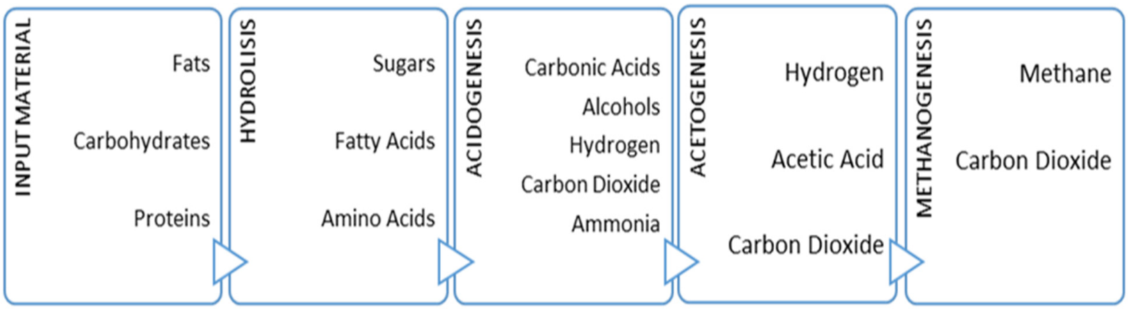

Figure 1: Phases of anaerobic digestion process [11].

Recent practice prefers a combination of substrates, called co-digestion, which has led to a higher gas production per ton of substrate [12]. Livestock manure is a cost-effective and viable feedstock for biogas production, but differences in animal digestive systems, nutrition, or, manure storage mechanisms result in different or most often lower biomethane production. Industrial waste, or generally waste from food industries, has been commonly used in bioreactors as a result of its chemical properties and biodegradability. Livestock manures generally provide a lower methane yield due to higher ammonia-inhibiting compounds and food by-products rich in lipid content (kitchen waste) have a higher methane yield. A low C/N ratio for livestock manure is combined with carbon-rich feedstock to achieve satisfactory results in biomethane yield [23] and also to satisfy the nutritional requirement of the microorganisms. Figure 2 shows a graphical representation of the substrate types used in anaerobic digestion posing good biomethane yield in mL/g volatile solids (VS).

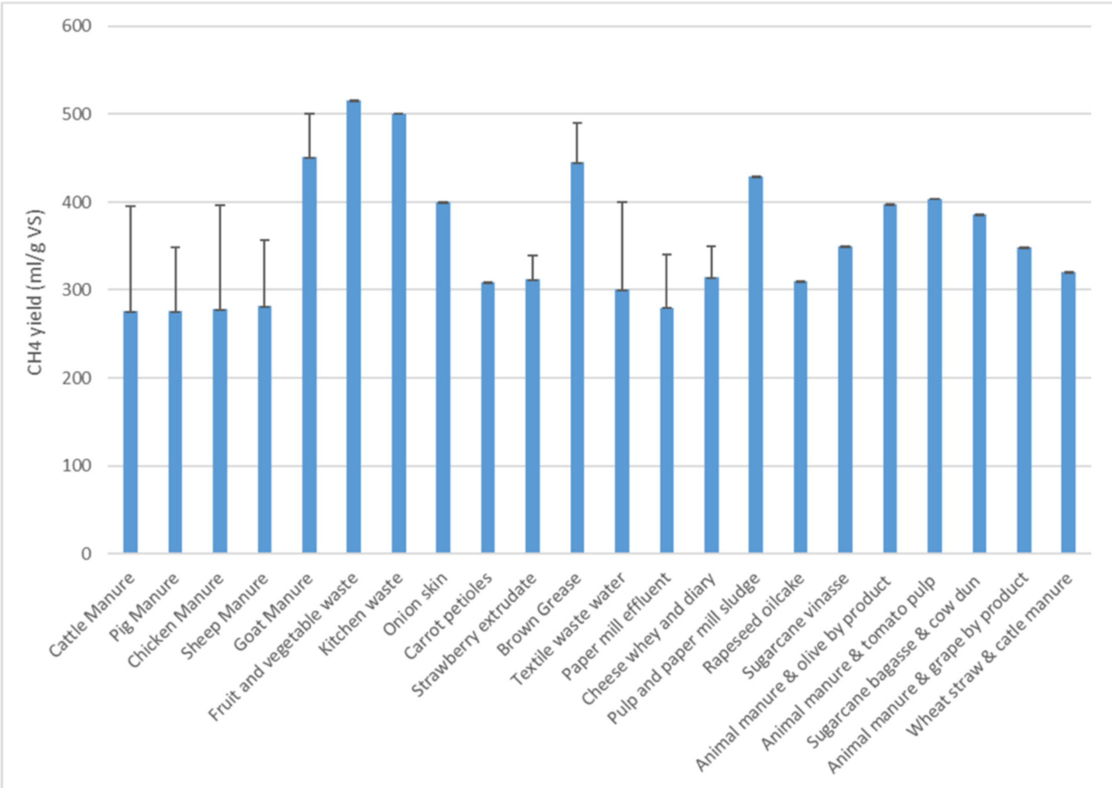

Figure 2: Biogas yield from different substrates with biomethane yield above 200 mL/g VS [24].

To prevent explosions from methane accumulation or to prevent the loss of methane into the atmosphere, landfill gas collection systems are implemented. The collected gas is often used in internal combustion engines or gas turbines to create electricity instead of burning in furnaces or boilers [25]. Although biogas production is not toxic, the presence of CO_2 and N_2 negatively affects the calorific value of the gas, and CO_2, H_2S, and water vapour form corrosive conditions for the equipment that damages it [16]. Pretreatment is also used to overcome the problem of digestion. Physical pretreatment reduces the particle size, resulting in an increase in surface area and a decrease in the degree of polymerisation. The application of different chemical compounds to accomplish a disruption of biomass structure through interaction with intra and inter-polymer bonds can be brought about by chemical pretreatment of biomass. Figure 3 shows a pictorial representation of the working of a biomethane plant.

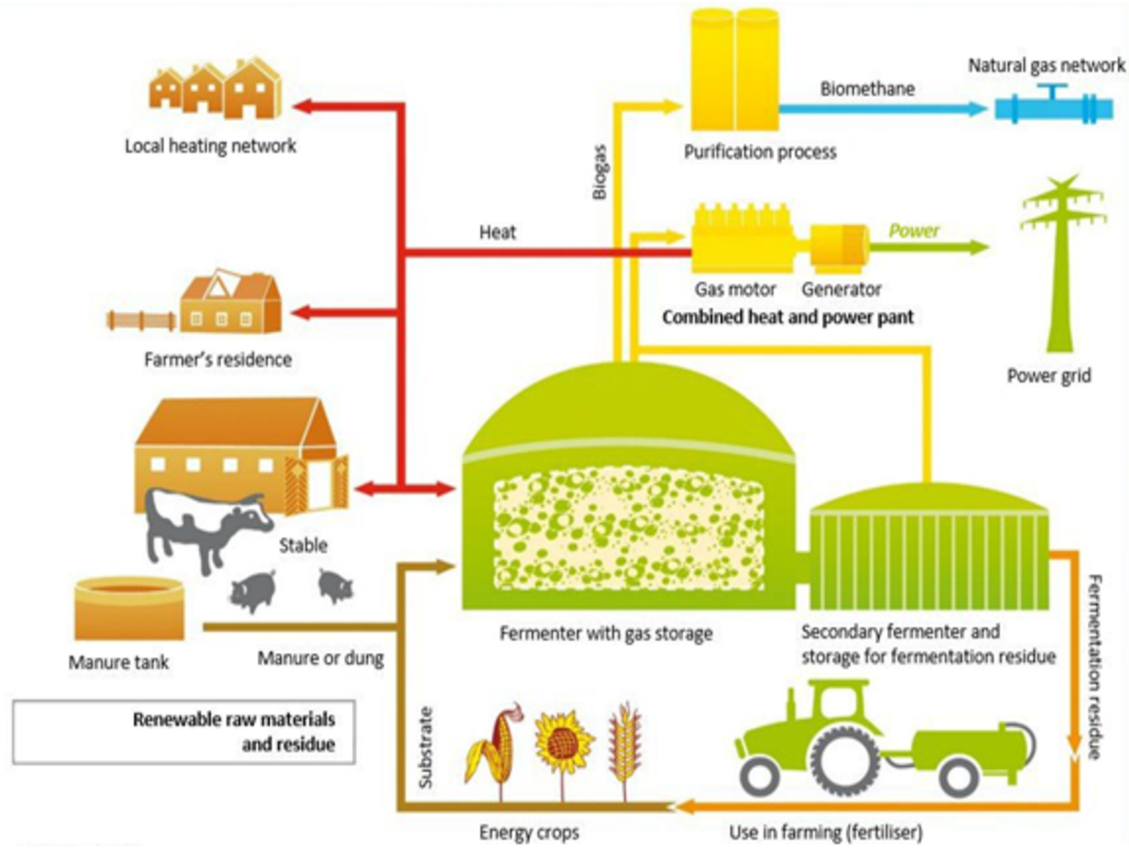

Figure 3: Pictorial representation of the working of a biomethane plant. Source: Clean Energy Wire (Copyright: Creative Commons 4.0)

2.2 Schematics of biogas plant:

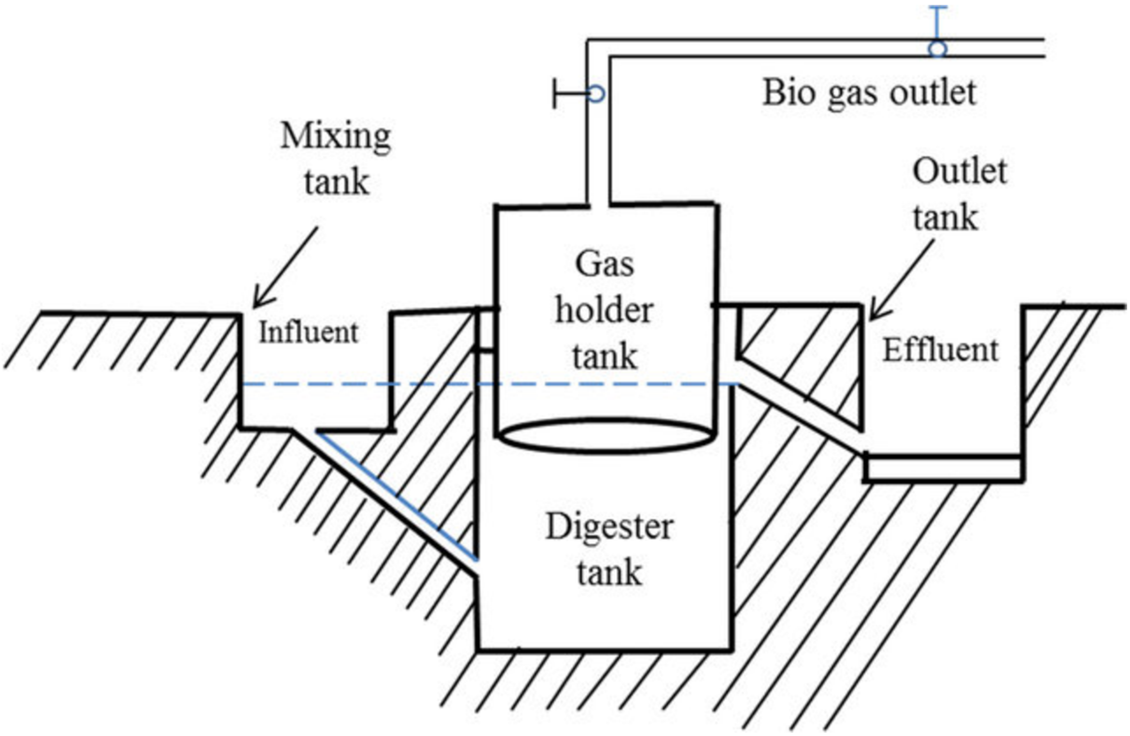

Figure 4: Simple schematic of a biogas plant.

Figure 4 given above represents a schematic diagram of a simple biogas pant. A biogas plant contains an airtight underground digester tank, a gas holder, mixing devices, and gas regulator valves. Biogas production technology has two-stage and one-stage biogas complexes. One-stage technology is used for most of the substrates and this technology is considered as a base. Two-stage technology is used for substrates that are rapidly decomposed and have a tendency to oxidise. Two-stage technology differs from one-stage technology by the presence of an additional hydrolysis reactor. Figure 5 represents different parts of a biogas plant of BITECO biogas.

The base biogas plant scheme consists of the following components and structures:

1. Receiving tank

2. Heating system

3. Mechanical agitators

4. Biomass supply system

5. Fermenter

6. Gas storage tank

7. Dome of rubberized PVC for protection of the gas storage tank

8. Gas offtake system and gas supply system with the condensate drainage system and sulphur recovery system

9. Separator

10. Lagoon or storage tank for liquid fertilizer

11. The automation system, the system of the process display and control

12. Heat supply station

13. Co-generator

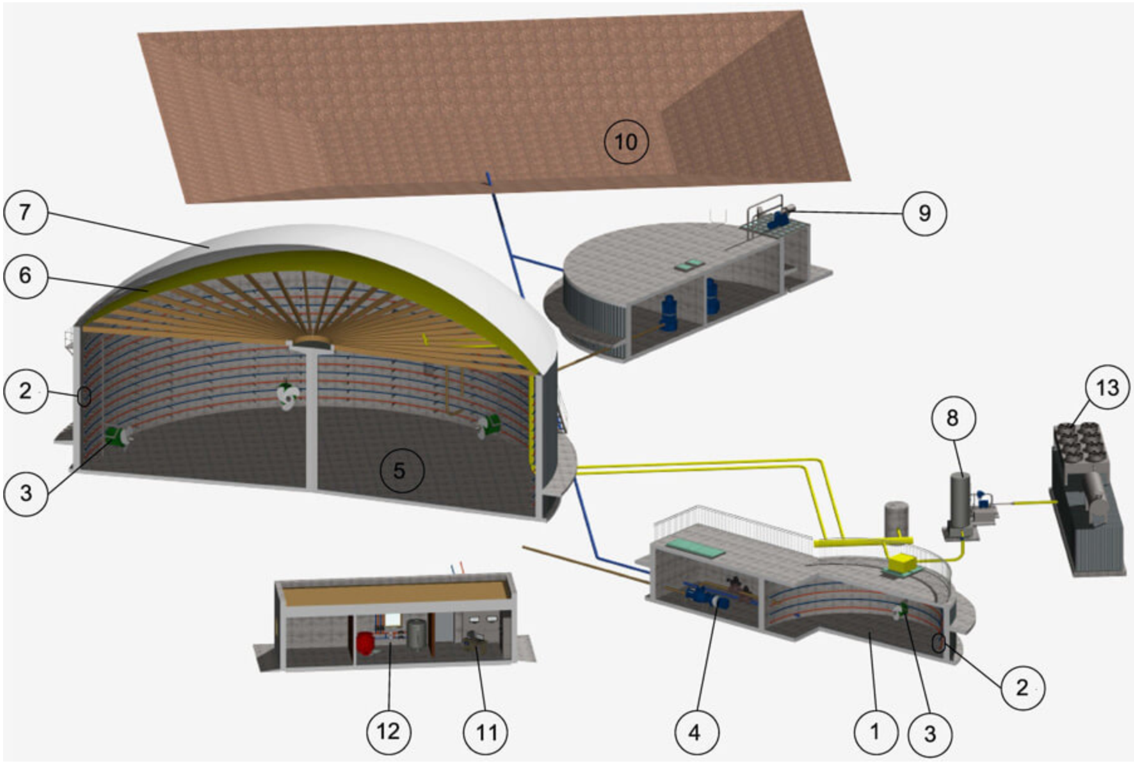

Figure 5: Schematic of one-stage or base biogas plant (BITECO Biogas) [26].

Operating principle:

The principle of biogas production aims to achieve maximum automation and minimum human labour. Wastes enter receiving tank (1), they are primarily accumulated, heated (2) and mixed (3). Raw material supply in the fermenter (5) takes place 4-6 times a day by using special pumps. Fermenter (5) is a gas-tight, sealed tank. To maintain a stable temperature, the fermenter inside is equipped with a heating system on the bottom and the walls (2) and for cold climates, insulation is present on the outside. The substrate is continuously stirred by using low-speed mechanical agitators (3) ensuring careful and complete mixing. A mechanical, hydraulic, or pneumatic system can also be employed according to the type of the substrate. The frequency of discharge of the fermented substrate is the same as that of loading. The whole biogas plant is controlled by signals from the automation system (11). Biogas is collected in a gas-storage tank (6) and is used as a gas-tight cover for the fermenter. Outer dome (7) has a high ultraviolet resistance, resistant to arson, and is highly extensible. Biogas is released using pipeline (8) equipped with automatic condensate drain and safety devices protecting the tank from excess pressure. The biogas is continuously supplied forward from the gas tank (6) to the biogas purification system. The refined substrate after the installation goes to the separator (9). Mechanical separation works for 4-6 times a day and the fermented remains from the fermenter on solid and liquid biofertilizers. All equipment is controlled automatically by the automation system (11). The technology of the production of biogas has two modes of system management and controls like program timing control and automatic control systems are used. The program timing control of the stages is performed at time intervals and synchronized between the systems. Automatic control systems work on the principle stated before.

2.3 Global energy sources and the shift toward renewable energy:

Energy plays an important role in economic growth, progress, and development as well as poverty eradication and security of any nation. The growth of the economy is crucially dependent on the long-term availability of energy from sources that are affordable, accessible, and environmentally friendly. Security, climate change, and public health are closely interrelated with energy [27]. The contribution to sustainable economic growth, job creation, better public health, and more equality, particularly for the poor and most vulnerable communities around the world is brought about by shifting from fossil fuels to renewable energy which also cuts emissions. The burning of charcoal, organic wastes and crop residues was an important source of energy for a long period of time. Bioethanol and biodiesel, fuels made from crops such as corn, sugarcane, hemp, and cassava are key transport fuels in many countries. Figure 6 represents the production of energy from biofuel in the year 2021. The living standard of a given country can be directly related to the *per capita* energy consumption. The world's energy crisis is due to rapid population growth, a decrease in natural resources such as fossil fuels and an increase in the living standards of societies. Energy supports the provision of basic needs such as cooked food, comfortable living temperature, lighting, use of appliances, piped water, health care, educational aids, communication, and transport. Energy also boosts productive activities including agriculture, commerce, manufacturing, industry, and mining. The lack of access to energy contributes to poverty and deprivation, which ultimately leads to economic decline.

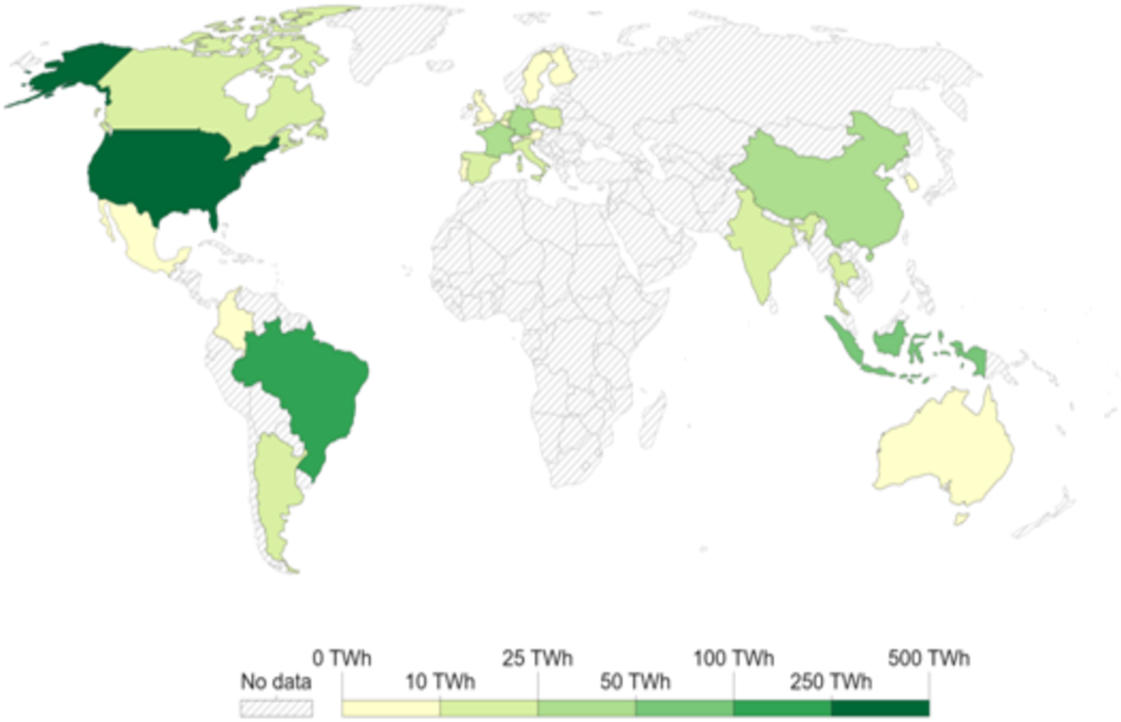

Figure 6: Pictorial representation of biofuel energy production [13].

The key drivers for energy transition worldwide are climate change and air pollution. Local air pollution is the main driver in China and India and also in Europe largely related to energy supply and use. Local air pollution can in certain cases be tackled with end-of-pipe technologies but this is not the case with bulk of CO_2 emissions from energy use. The energy transitions can reduce emissions substantially ensuring that sufficient energy is available for economic growth. The Sustainable Development Goals (SDGs) adopted by the United Nations General Assembly (UNGA) in 2015 provides a powerful framework for international cooperation to achieve a sustainable future. The global goal on energy has three key targets: ensure affordable, reliable, and universal access to modern energy services, increase the share of renewable energy in the global mix, and double rate of improvement in energy efficiency [28].

About 80% of the global population lives in countries that are importers of fossil fuels which makes them vulnerable to geopolitical shocks and crisis. The International Renewable Energy Agency (IRENA) estimates that 90% of the world's electricity can and should come from renewable energy by 2050. The cost of electricity from solar power fell by 85% between 2010 and 2020 and wind energy by 48-56%. Cheap electricity from renewable sources could provide 65% of the total global electricity supply by 2030 which could decarbonise 90% of the power sector by 2050 massively cutting carbon emissions and helping mitigate climate change. According to World Health Organization (WHO), about 99% of people breathe air that exceeds the air quality limit and threatens their health with more than 13 million deaths around the world each year due to environmental causes like air pollution. The unhealthy environment is caused due to burning of fossil fuels which led to $2.9 trillion in health and economic costs. Thus, switching to clean energy such as wind and solar energy will not only help to address climate change but also pollution and health. Every dollar of investment in renewables creates three times more jobs than in the fossil industry. It is estimated that by 2030, about 5 million jobs will be lost in fossil fuel production with the creation of 14 million new jobs in clean energy. This will further increase the jobs for another 16 million workers to take on new roles in manufacturing electric vehicles and appliances or innovative technologies like hydrogen taking the total jobs to 30 million. About $5.9 trillion was spent on subsidizing the fossil fuel industry in 2020 compared to $4 trillion which needs to be invested in renewable energy by 2030 which is more economical compared to investments in fossil fuels. The investment in renewable energy will cause some financial and technical problems for some countries but will pay off as the reduction in pollution and climate change impacts will save $4.2 trillion every year until 2030. The energy generated by different countries from renewable source of energy is depicted in figure 7 and a general comparison is also shown in figure 8 regarding the energy generation from various renewable sources.

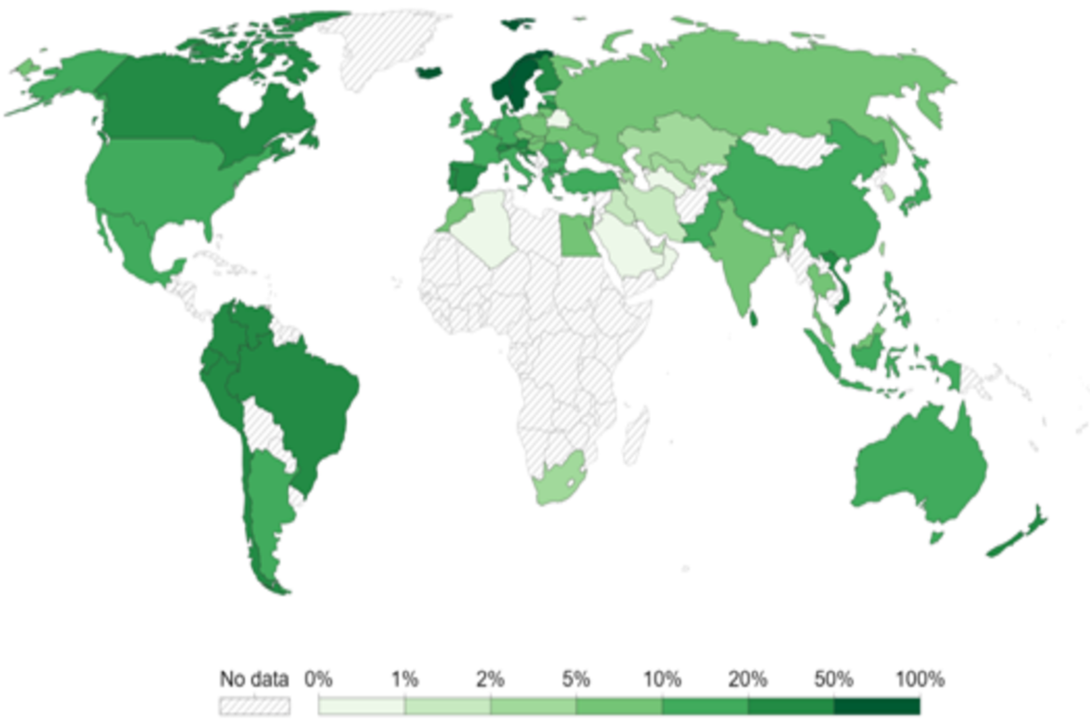

Figure 7: Pictorial representation of energy generated from renewable sources by different countries.

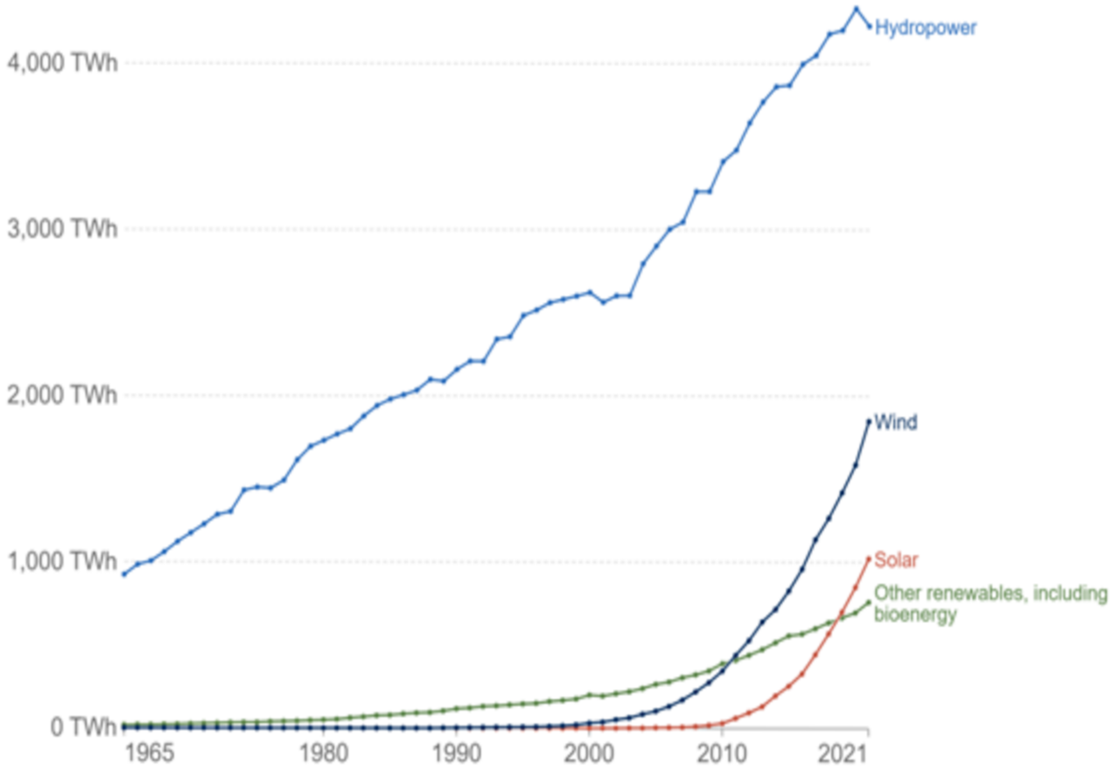

Figure 8: A general comparison of the energy generated from hydro, wind, solar, and other renewables.

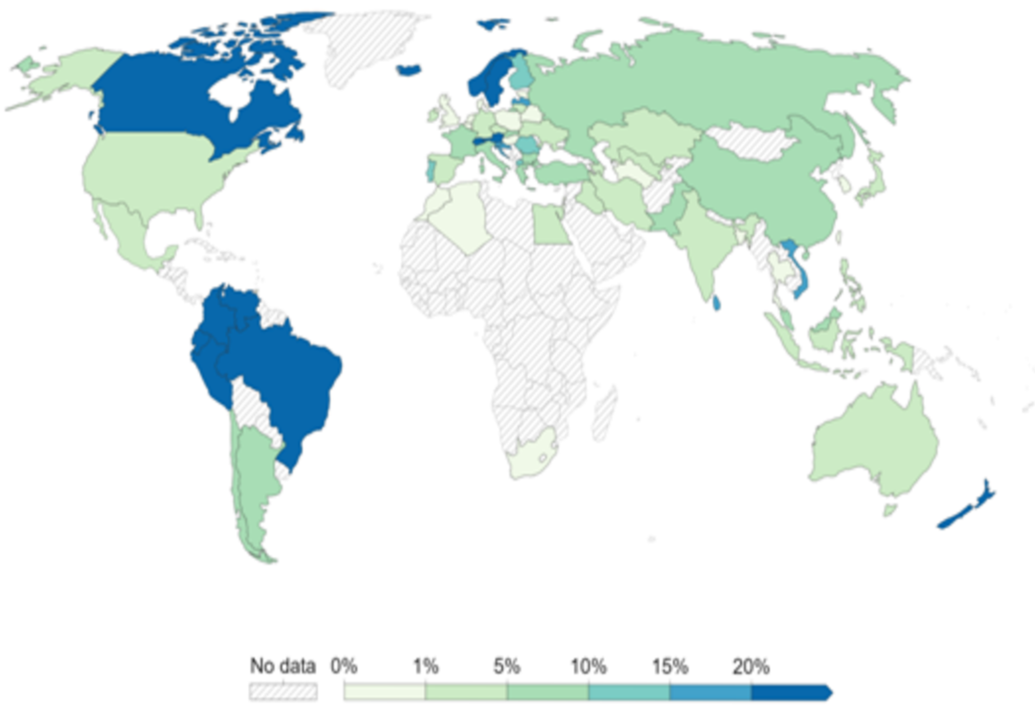

Figure 9: A pictorial representation of energy derived from water or hydroelectric power stations.

In 2019, around 7% of global energy came from hydropower. Hydroelectric power has been one of the oldest and largest sources of low-carbon energy accounting for more than 60% of renewable generation. Figure 9 shows the representation of energy generated from hydroelectric power stations in various countries.

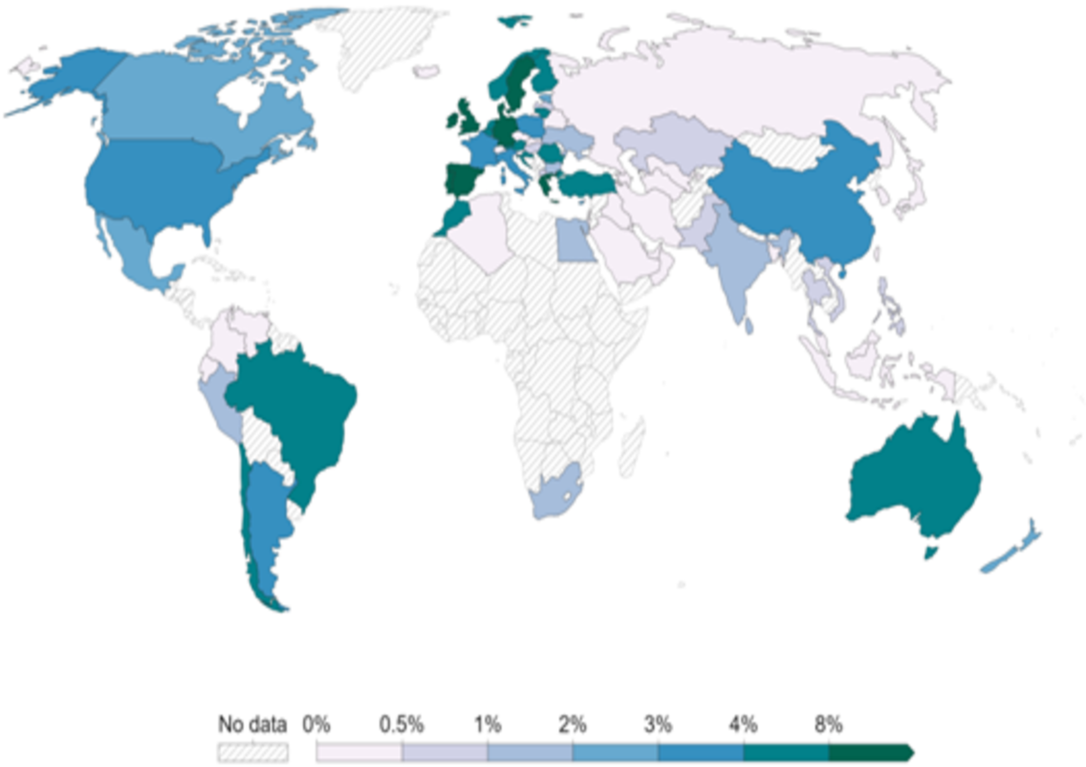

Figure 10: A pictorial representation of energy generated from wind energy.

In 2019, around 2% of global energy came from wind. Wind energy also contributes to the generation of energy as a sector in many countries as represented in figure 10.

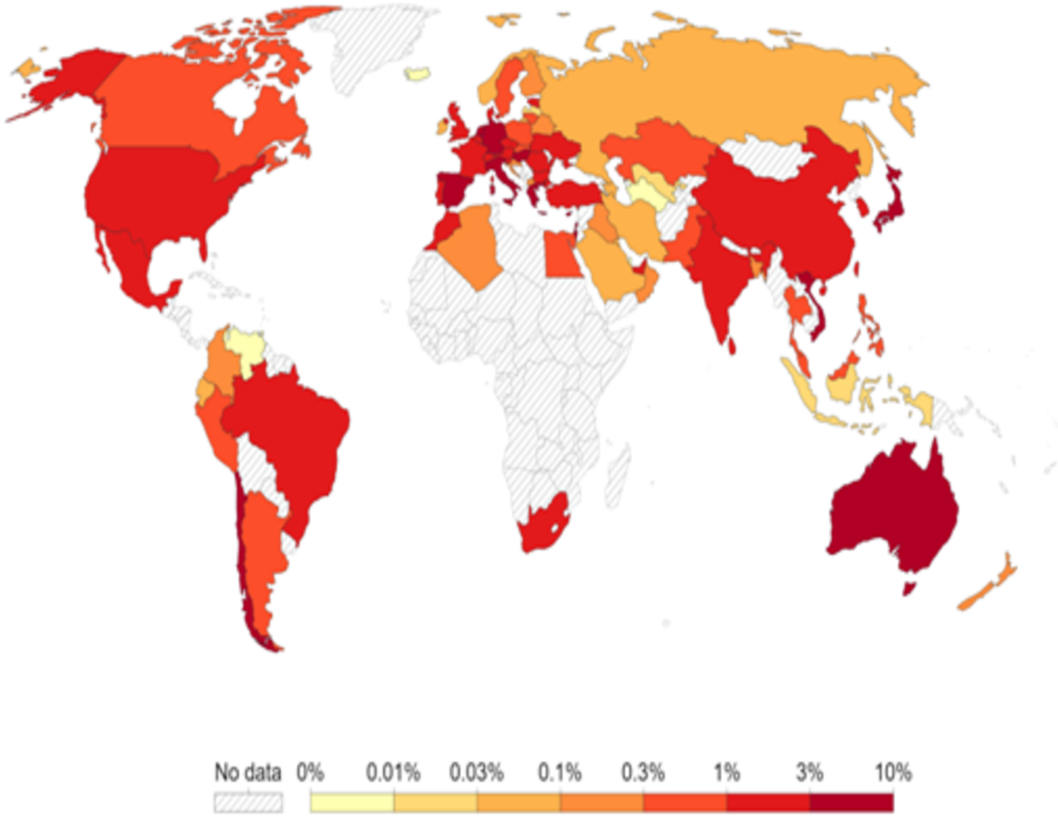

Figure 11: A pictorial representation of energy generated from solar power in 2021.

In 2019, around 1% of global energy came from solar technologies.

By 2026, global renewable electricity capacity is predicted to increase more than 60% from 2020 levels to more than 4800 GW, which is equivalent to the total global power capacity of fossil fuels and nuclear combined in the year 2021. The share of senergy generated from solar power by various countries is depicted in figure 11. The amount of renewable capacity added from 2021 to 2026 is expected to be 50% higher than that of the 2015 to 2020 period. The growth of renewables is said to increase in all regions compared with the 2015-2020 period. China is the global leader in the volume of capacity additions and it is expected to reach 1200 GW of total wind and solar capacity in 2026. India is set to come to the top in terms of rate of growth, doubling new installations compared to 2015-2020. Europe, the USA, China, and India are the top four markets that account for 80% of renewable capacity expansion worldwide. Despite increase in prices limiting the growth, global biofuel demand is said to surpass all the previous levels with Asia accounting for 30% of new production. India is expected to become the third largest market for ethanol worldwide, only after the United States and Brazil.

2.4 Biogas as an alternative source of native energy in Nigeria:

Fossil fuels meet the demand of 85% of global energy which is said to grow by about 50% in the year 2025. The combustion of fossil fuels leads to global warming and climate change and also environmental pollution. The transition of energy and renewable energy will promote proper waste management [29], energy access, and a green economy [30]. Renewable energy is essential for Nigeria to achieve its stated nationally determined contributions and will also have socioeconomic benefits. Nigerians depend on fuelwood or firewood for their energy needs, which represents about 70% of primary energy consumption, and electricity is just 0.52% with only 40% of Nigerians having access to electricity. Biomass anaerobic digestion technology can be used for fertiliser production to improve soil nutrients and support high crop production, as it is infinitely available and is not harmful to the environment, so it can be used to generate electricity, heat or fuel for power. The Nigerian Renewable Energy and Energy Efficiency Policy (NREEEP) aims to add 23,000 MW of renewable energy capacity by 2030 which will account for 10% of the country's energy. Residues are generated during agricultural production, harvesting, and processing such as weeds, corncob, rice husk, rice straw, litter, and livestock. Without suitable treatment, these wastes create many problems and adversely affect human health and well-being, which can be used as feedstock for industrial processes and also for energy production [31].

Utilization of waste for energy production will help to reduce the problem of poor energy supply in Nigeria [32] and 2nd generation of biofuels produced from agricultural residues are actually carbon neutral or even carbon negative and can benefit the country to a large extent. Many studies have been conducted on the utilization of biomass for energy production in Nigeria such as biomass residues and their bioenergy potential, agro-bioenergy potential to reduce emissions and mitigate climate change, and bioethanol production from biomass feedstock [32]. Since 1973, Nigeria has been producing ethanol from cassava feedstock although on a very small scale. Poor waste management in Nigeria led to greenhouse gas emissions with 491,000 tons of methane produced in 2015 which is said to increase to 670,000 tons by 2030. These have compelled to use of renewable biomass for bioenergy production. The main advantages include zero waste generation, reduction in emissions, economic development, and the use of biofuels, biomaterials, and biochemicals [33]. Estimates show that the hybrid incineration and anaerobic digestion system will reduce the potential for global warming of Nigeria's waste management by 75.3-84.8% [34]. Per capita power consumption in Nigeria (156 kWh) is significantly lower than other developing countries like Malaysia (4114kWh), South Africa (4405 kWh), and Venezuela (3413 kWh) [35] making Nigeria to be world's leading importer of gasoline and diesel.

Biogas is currently acceptable energy worldwide. Biogas for energy is a growing trend in about 50 countries, especially China, India, Sweden, Germany, and the UK. Several European countries are expanding their total share of power generated by using biomass. Biogas is the key to China's rural development. In 2007, 26.5 million biogas plants with a combined output of 10.5 million m^3 biogas and household digesters were found all over the country. This technology is sustainable, simple, and affordable, ensuring energy independence and improved energy security resulting from decentralised electricity generation. Nigeria still has some factors which limits the deployment of the biogas technology framework. Some of the factors are insufficient training, information, and education resulting in a lack of technical expertise in biogas technology, lack of regulation, lack of financial incentives, and lack of framework for promoting bio-energies. The generation of 25.53 billion m^3 of biogas from organic wastes channelled into anaerobic digestion and the by-products of such activities can be used for the production of 88.19 million tons of biofertiliser annually will solve the energy issues of the country. These methods and cheap sources of biowaste are found in many places in Nigeria, paving the way for biogas to be a potential solution to the basic challenges of waste management and energy. According to a study, when the digester size increases, the initial cost of production for biogas plants will decrease and the number of digesters required for a specific area will also be reduced. Thus, the method could become an authentic source of energy and a renewable energy substitute that also provides agricultural biofertiliser. For Nigeria to progress and succeed in its energy transition strategy it will be necessary to continue to develop its significant gas reserves and resources while at the same time progressing renewable energy sources mainly solar at the local level, for example through the establishment of micro-grids. Different socioeconomic and developmental needs of Nigeria compared to developed countries must be recognized. Investors and international lenders will need to continue to play a critical role in financing the development of gas as a transition fuel for Nigeria. The participation of bilateral funds, development b, banks and institutions, and infrastructure funds coupled with innovative and flexible capital structures that know the risks, timeframes, and rewards of the financing of gas projects will remain the key to developing the opportunities for Nigeria's renewable resources.

2.5 A review of medium-scale biogas technology in Nigeria:

With the shocks of oil prices in 1970, increased attention has been paid to developing technologies using new and renewable energy sources. Biomass fuels are used daily in half of the world's households as energy for cooking and heating, which is important for developing nations because they do not have access to sources such as crude oil, natural gas, and coal. The new and renewable sources offer attractive prospects as they are pollution-free, unlimited, and cheap. India and China are the pioneers in the development and application of anaerobic technologies for the production of fuel gas and waste management. With the implementation of household-size biogas digester technology in China in 1950, they have followed a consistent program of development, technical support, and assisted technology with the result that the technology is widely adopted to supply fuels for rural household lighting and cooking. Biogas is of great interest mainly in the Asia and Pacific region and is used in Tanzania, Burundi, Cameroon, and Nigeria. At least about 6.5 million and 1.8 million biogas plants are already in use in China and India, implying that approximately 3.8% and 0.7% of the population in China and India use biogas. In Africa, biogas producing units are present in almost all regions of the continent, which range from small to medium digesters with gas producing capacity of less than 100 cubic metres to largest digesters of greater than 100 cubic metres. Table 2 shows the level of technology development in different countries of Africa.

Table 2: Countries with biogas-producing units in Africa [36, 37].

Country	**Geographical characteristics**		**Region**	**No small/medium digester (≤100 m^3)**	**No of Large scale digester (>100 m^3)**	**Level of technology development**
	Landlocked	**Coastal**				
Botswana		*	Southern Africa	Several	Few	Low
Burkina Faso	*		West Africa	Few	-	Low
Burundi	*		Central Africa	Several	Several	High
Cameroon		*	Central Africa	Few	-	Low
Congo-Brazzaville		*	Central Africa	Several	Few	Low
Cote d'Ivoire		*	West Africa	Several	Few	Low
Egypt		*	North Africa	Several	Few	High
Eritrea		*	East Africa	Few	-	Low
Ethiopia	*		East Africa	Few	-	Low
Ghana		*	West	Several	Few	High

			Africa			
Guinea			West Africa	Few	-	Low
Kenya		*	East Africa	Several	Several	High
Lesotho	*		Southern Africa	Few	-	Medium
Malawi	*		Southern Africa	Few	-	Low
Mali	*		West Africa	Several	Few	High
Morocco		*	North Africa	Several	-	Medium
Namibia		*	Southern Africa	Few	-	Low
Nigeria		*	West Africa	Few	Few	Low
Rwanda	*		Central Africa	Several	Few	High
Sierra Leone		*	West Africa	Few	-	Low
South Africa		*	Southern Africa	Several	Several	High
Sudan		*	East Africa	Few	-	Low

Swaziland	*		Southern Africa	Several	-	Medium
Tanzania		*	East Africa	Several	Several	High
Tunisia		*	North Africa	Few	-	Low
Uganda	*		East Africa	Few	-	Low
Zimbabwe	*		Southern Africa	Several	Few	Medium

Nigeria distributes about 3,000 MW of electricity for consumers which is far less than the estimated 36,000 MW required. Nigeria has a huge electricity deficit that cannot be met from the existing hydroelectric sources and consumption of electricity is ranked 71st in the world. In Nigeria, the use of biomass for energy has majorly been for cooking and heating and not electricity generation. The livestock population of 289.7 million generates about 61 million tonnes of waste per year, 50% of which can generate 40 MW of electricity in a year when subjected to biological gasification. According to the Energy Commission of Nigeria's projection, biomass will add 3,345 MW of electricity by 2025 although Nigeria currently has no single biomass-powered electricity generating plant despite the abundance of biomass. Currently, biofuel production and its use are almost zero except for a few biogas plants. The demand for renewable fuels and electricity will increase from 0 to 17% in 2030. The share of biofuels as renewable fuel in transport is expected to increase by about 90%.

2.6 Biogas plant: a tool for rural development in Nigeria:

Energy generation remains one of the biggest challenges of developing countries like Nigeria. About 80 million out of 180 million Nigerians living in 8000 villages lack access to electricity according to the world bank report and due to this the lack of stimulation of small and medium-scale enterprises in rural communities is a major factor responsible for rural-to-urban migration. Most villagers, as well as low-income earners in towns and cities, also depend on fuelwood posing a serious threat to the environment. For example, long-distance transport from other parts of the country compensates for the deficit in northern Nigeria's fuelwood. Due to three major problems, they do not have any option. Firstly, electricity is not available in most villages and therefore it cannot be used as a fuel. Second, the scarcity of popular cooking, fossil fuel and kerosene, caused artificially by unpatriotic ways directed to black markets and neighbouring countries, causes the price of kerosene to be very high, sometimes as much as eight times the original price. Thirdly, liquefied petroleum gas is so expensive that it is out of reach of the common family. Therefore, it is necessary to take advantage of some ways to conserve both resources and the environment by introducing simple technologies such as biogas generation. Several African countries use wood as traditional fuel which accounts for up to 90% or more of primary energy consumed. Environmental dangers such as deforestation, erosion, flooding, and desertification are posed due to this, which has serious effects on farmlands, ranches, and fishing waters, as well as distortion to the natural habitat that threatens the existence of wildlife. Fuelwood collection also affects rural families in their lifestyle where they spend a lot of time collecting wood instead of engaging in some constructive activities like schooling or trading.

The feasibility and practicality of a biogas plant in Nigeria can be assessed under the following points:

a) **<u>Raw materials availability and accessibility</u>**- There are large amounts of biomass from agriculture, animal husbandry, and household waste in the country, and biogas raw materials such as animal and poultry dung, crop residues, and by-products from slaughter houses, crop processing plants, and agrofactories are easily available at little or no cost. The energy content of 19.1 million tonnes of dung produced by 53.7 million domestic animals in Nigeria alone is enormous, which amounts to about 37.7 PJ/year if one tonne of refuse produces an average methane yield of 98.05 m^3 with at least calorific value of biogas as 18 MJ/m^3. The cow dung produced by cattle of non nomadic farmers is accessible and relatively purer because the stead floors are paved and are often poorly evacuated and disposed of which can be a good digester of raw material. More cow dung will be accessible for biogas production when the long-term efforts of the government to settle nomadic cattle owners become successful. The number of goats and sheep and the amount of dung they produce is also high which is less contaminated compared to cow dung also the contribution of dung by several families to feed a batch-fed digester is possible. The use of poultry droppings mixed with other raw materials is also an option for biogas production. Agricultural residues that are available in substantial quantities include rice, wheat straw, stalks of guinea corn, cotton, maize, millet, groundnut, cowpea vines, and shells. Medium-scale crop processing residues whose heaps are common like rice husks, bran of rice, guinea corn, and maize. Crop residues are seasonal so they are required to be stored for their use in bioenergy production. Much of the residues are disposed of by burning and dumping, which is not environmentally friendly. By-products of laughter houses in major cities pollute the air and constitute breeding grounds for pathogens because they are not properly disposed of and so harnessing them for biogas production will provide energy as well as improve public health and the environment.

b) **Technical and financial aspect-** The technical groundwork needed before a full-scale program takes off that is research and development can be handled by numerous universities and research institutes. The skilled labour required is also available to develop digester models. Some aspects that need to be addressed by the research and development department are the availability of feed material and the ratio of water and waste, which will to the be decreased due to scarcity of water in the dry season, which is a common phenomenon in semi-arid regions of Nigeria. The construction materials also easily available such as bricks and digester accessories, and with appropriate supervision, construction can be undertaken by the indigenous bricklayers and masons.

c) **Climatic, cultural and social settings-** Temperature is a major determinant in the overall anaerobic digestion process of biogas raw material working at about 30°C. The Nigerian climate is favourable for biogas generation. Parts of the country that have high concentrations of animals and farmlands have high temperatures where the high maximum temperature averages 40.5°C. With this temperature, it is possible to produce biogas by mesophilic digestion during most of the year without incurring additional input energy costs through heating.

In Nigeria, like most other African countries, there exists a high level of intra- and inter-community social interaction, especially in rural areas. With this, it is possible to establish and run joint- and community-biogas plants, e.g. for small and medium-scale co-operative businesses such as kosai and gari production, blacksmithing, aluminium smelting, etc., cooking and lighting in schools or hospitals. The villagers raise funds for pump spare parts for the pumps installed with the help of UNICEF and so a similar method can be used to install, operate and maintain community biogas plants, which are more practical than single-family plants. The introduction of simple and cheap biogas technology into Nigeria is feasible as there is abundant raw material for the production of gas as well as favourable climatic conditions. With this technology, the depletion of fuelwood, which is inflicting untold damage to the environment, will be checked and the reserve of petroleum energy will be increased since less domestic petroleum fuel will be used, improving the overall economy of Nigeria. With the full support of the government at the federal, state and local levels for the construction of a biogas plant and with all the available biomass, the problems of energy shortage and environmental destruction will be addressed.

In Benin metropolis, Nigeria, food waste of about 305.075 tonnes is generated per day which yields biogas of about 28,836.91m3/day or 49.023 MW of electricity/day according to the study carried out by Akhator et al. [38]. With this amount of biogas produced per day, the energy demand of about 24,076.91 households in Benin can be met daily. Therefore, the production of biogas from kitchen/food wastes using anaerobic digestion technology is very feasible in Nigeria.

2.7 Medium-scale biogas plants toward a solution for green waste management in Nigeria:

Biomass can be used as a green energy resource in Nigeria which is found in abundance. The biomass available includes agricultural residues, animal waste,waste, municipal wastes, and water hyacinths as per Uzoma et al. 2011 [39]. These biomasses, which are usually discarded in the country to the detriment of humans, animals, and the environment, can be processed into biogas, which could be used for off-grid energy generation using biogas plants. It is worth noting that the use of these biomasses for electricity generation poses no threat to food security and forest preservation as they are considered useless materials that should be discarded. Table 3 shows estimated biomass resources in Nigeria.

Table 3: Biomass resources in Nigeria

Biomass	**Quantity per day (tonnes)**
Agro-residues	109,401.10
Forest and wood processing residues	14,246.58
Animal residues	227,500
Organic municipal solid waste (food waste)	34,442.80
Combustible municipal solid waste	16,790.22

Source: [40].

For example, 1 kg of fresh animal waste produces approximately 0.03 m^3 of biogas (Ben-Iwo et al. 2016) [41], therefore, Nigeria can produce approximately 6.8 million m^3 of biogas per day from fresh animal waste. The total amount of biogas obtainable can be estimated using the following equation given by Kigozi et al. 2014 [42].

$$TBO=AFW \times VS\ (\%) \times BY$$

Where, TBO=Total Biogas Obtainable (m^3), AFW=Amount of Food Waste (tonnes), BY= Biogas Yield (m^3/t VS). VS (Volatile Solids) is 94.90% of TS (Total Solids) and TS is 27.14% of food waste quantity, biogas yield from food waste is about 367 m^3/t VS. By applying these values in the equation, about 3.3 million m^3 of biogas per day can be obtained from food waste in Nigeria. This gives about 10.1 million m^3 of obtainable biogas from both animal and food wastes generated per day. 1 m^3 of biogas can be converted to about 1.7 KW of electricity, so 10.1 m^3 of biogas would generate approximately 17,170 MW of electricity. According to Akhator et al. 2016, the combustion of 3.6 tons/h of solid waste in a steam power facility can generate 1.4 MW of electricity [40].

Table 4: Power potential of biomass resources in Nigeria.

Biomass	**Power potential (MW)**
Agro-residues	14,889.65
Wood processing residues	562.215
Animal residues and food waste	17,170
Combustible municipal solid waste	6,529.53
Total	**39,151.395**

Hence, 16,790.22 tonnes of combustible solid waste would generate about 6,529.53 MW of electricity. According to Simonyan and Fasina (2013), about 14,889.65 MW and 562.215 MW can be obtained from agro-residues and wood residues, respectively [43]. This gives a total of about 39,151.395 MW of electricity, which translates to about 939.634 GWh of energy for biomass. Table 4 represents the power potential of biomass resources in Nigeria.

2.8 Factors and challenges for the adoption of biogas technology in Nigeria:

The adoption and implementation of biogas projects in Nigeria are hindered due majorly due to resistance to change, inadequate research, training, and expertise in technology, lack of investment incentives and trade, insufficient funding, and lack of policy, strategy, and regulations, despite the presumptions that biogas plants last for 100 years. Figure 12 shows a visual pictorial representation of various factors which is responsible for adopting a biogas plant in Nigeria.

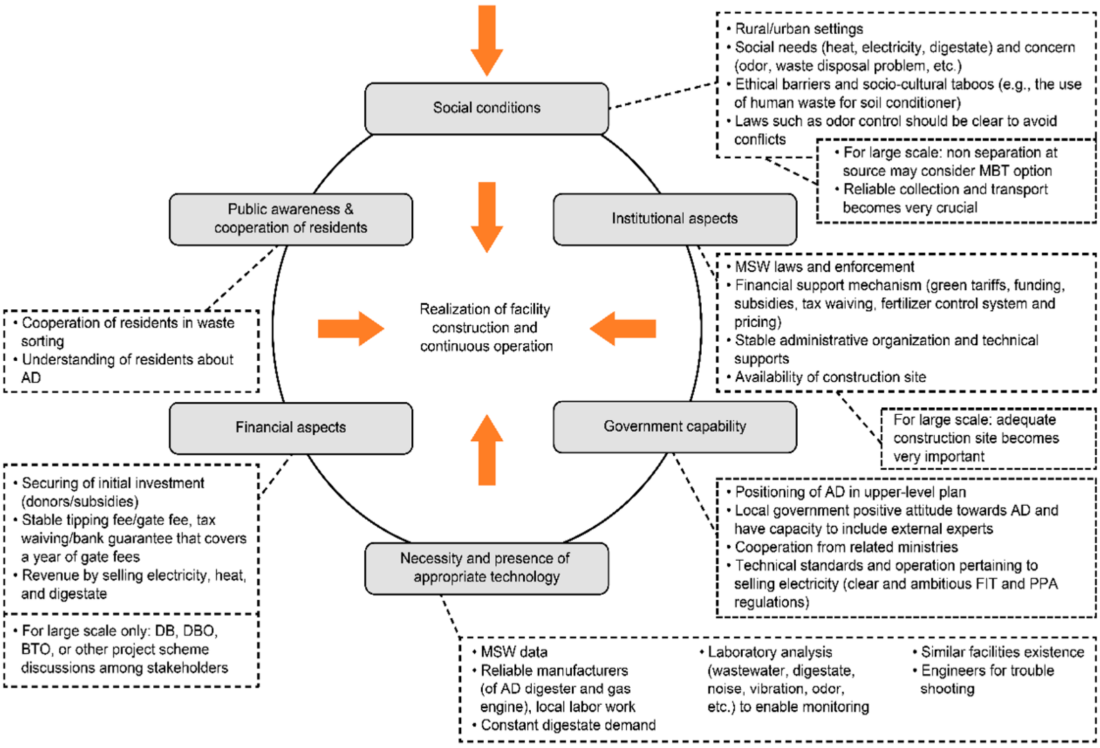

Figure 12: Representation of various factors responsible for adopting a biogas plant.

There are various technologies for the production of bioenergy for heat and power generation in Nigeria, but the deployment of these technologies in most African nations including Nigeria has achieved very little success. The adoption of biogas technology in Nigeria is hindered by some barriers that cause failure and low-level implementation of biogas technology development in Nigeria. Some of the challenges and problems faced by Nigeria in adopting biogas technology are:

- **Limited access to funding:** Acquiring a biogas plant involves a huge amount of investment in terms of operation and maintenance costs. Average Nigerians in the rural community depend on subsistence farming for a living, and the income accruable from such farming operations is not sufficient to acquire biogas plants. Hence, the most challenging barrier to the uptake and develop biogas technology in Nigeria is insufficient finance since loan facilities and inadequate government incentives. Financial institutions, such as the Central Bank of Nigeria, are unwilling to provide financial packages due to the high risks and the experience of low recovery [44].

- **Limited technical knowledge and infrastructural barrier:** In Africa, there is a fair technical experience with family-sized biogas systems, but this cannot be said for commercial biogas systems because of their large capacity and complexity. Higher skills and expertise are required for the conception, design, construction, and management of commercial biogas systems. The origin of the technical and infrastructural barrier of biogas deployment in Nigeria is the feedstock supply. The poor transportation system in Nigeria is capable of disrupting feedstock supply chains to the site of operation [45]. In addition, government failure to support bioenergy technology through energy policy, improper information dissemination on the economic feasibility of bioenergy technology, inadequacy in research and development activities, inadequate resource data, substandard product quality, many unresolved engineering problems, inadequate human and manufacturing capacities, lack of information on advanced production techniques, and many more are some of the setbacks recorded on the deployment of bioenergy technology. The cumulative effect is limited knowledge in bioenergy technology design, maintenance, and applications.
- **Poor grid network:** Another important issue affecting the deployment of biogas technology in Nigeria is the poor grid network. The grid infrastructure in Nigeria and some parts of Africa is not robust and has posed a serious challenge to existing

power plants. It also affects the capability of the grid network to access renewable energy power plants.

- **Lack of adequate policy and legislative framework:** The growth of Nigeria's energy sector has been delayed due to the lack of enabling legislation for the implementation of clean energy policies. The lack of policies and a legislative framework can slow the implementation of reliable and efficient biogas technology [44]. Presently, Nigeria as a nation does not have a well-detailed policy on bioenergy technology development, and the successful implementation of bioenergy technology in a country requires well-formed policies. For the development of feasible biogas technology in Nigeria, strong and supportive policies and a firm legal, regulatory and institutional framework are required. Furthermore, both private and public institutions need to be encouraged to make their policy to promote the use of energy efficiently.
- **Lack of proper awareness:** The attitude and perception of many people in Nigeria about biogas technology are not encouraging. This is due to poor information dissemination strategies compounded with low levels of education of people living in rural areas of the country and lack of access to modern day media. Also, awareness created about biogas technology and its benefits is not adequate. Most farmers and processing industries are ignorant of “energy generation and waste management” as the benefits and opportunities created by bioenergy technology [45]. If prospective end users are not well informed about their potential, then the implementation and optimal operation of renewable energy systems in any country becomes difficult. Rural people find it difficult to acquire relevant information about biogas technologies, so they are forced to use their well-known traditional ways of generating energy. If biogas technology is to be sustainable, all forms of

communication channels should be used for proper awareness of the benefits of employing biogas technology for energy generation.

- **Market barrier:** Biogas competes in rural areas with traditional solid biomass such as firewood and animal dung which are cheaper and readily available to use as fuel for cooking. In urban centers, there is competitiveness between biogas and low-price electricity from coal and natural gas-fired power plants. Due to tariff support from the government, electric power generated from renewable sources such as hydro, wind and solar is way cheaper than bioenergy generated from anaerobic digestion technology. That is, the cost of electricity from biogas technology is higher than that of other renewable sources. Furthermore, other waste treatment technologies such as composting and vermicomposting, which can also be employed for the treatment of organic municipal and industrial waste, compete with anaerobic digestion technology.

2.9 Organic waste as a source of fuel for biogas plants in Nigeria:

Biomass availability is widespread throughout the world and its distribution depends on location. In Nigeria, feedstock-producing biogas ranges from agricultural wastes to municipal solid wastes. Nigeria is also reported to produce biomass of about 144 million tonnes per year. Furthermore, most rural dwellers in Nigeria according to the US Energy Information Administration depend heavily on biomass such as wood, charcoal, and waste from animals and municipals to meet their energy demands [41]. Table 5 represents various feedstock and their major sources in Nigeria.

Table 5: Feedstock and its sources in Nigeria [6].

Agriculture	1)Animal manure 2)Energy crops 3)Crop residues 4)Algal biomass
Municipal solid waste	1)Sewage sludge 2)Kitchen waste 3)Night soil 4)Garden waste 5)Food remains
Industrial and Commercial	1)Food/beverage processing waste 2)Pulp and Paper 3)Slaughterhouse waste 4)Bakeries 5)Confectioneries 6)Pharmaceutical waste 7)Industrial organic waste water

Livestock waste: One of the major agricultural practices is livestock production which is the biggest source of animal waste. The amount of waste generated from livestock production depends on the type of animal rearing, methods of feeding, size of the animal, and breed [46]. Some common animal wastes are cattle, poultry, pig, sheep, horse, and goat manures. It was reported that pig and poultry manures are rich in protein while cattle manure contains a lot of lignocelluloses [47]. Nigeria as a nation produces, 6,800,000 m^3 of biogas per day from 227,500 tons of animal manure daily [48, 49]. Oyedepo et al. stated further that, 450.48 PJ is the estimated bioenergy potential of animal manure in Nigeria [48]. Table 6 shows the livestock population in Nigeria together with biogas yield. The table indicates that Nigeria has a large population of livestock that has resulted in the generation of a large amount of livestock manure. Improper disposal of this large quantity of manure could be harmful to the environment, and human and animal health. Manure/wastes from this large number of livestock when converted by anaerobic digestion can ease the burden of high energy demand in the country. For example, the estimated biogas potential per annum from cattle manure, poultry manure, swine manure, and goat and sheep manure is 6.25 billion m^3, 2.5 billion m^3, 0.92 million $m^{3,}$ and 2.3 billion m^3, respectively. These are huge energy resources that can easily boost Nigeria's energy supply.

Table 6: The livestock population in Nigeria together with biogas yield [50].

Livestock	**Population (x1000)**	**Daily dung generation (kg)**	**Biogas yield (m^3/kg dry matter)**
Cattle	20,773	8-50	0.20-0.24
Chickens	140,688	0.05-0.15	0.28-0.40
Pigs	7,506	1-4.5	0.37-0.56
Goats	78,037	1-5	0.25-0.37
Sheep	42,500	1-5	0.25-0.37
Camels	282	20	0.14-0.19
Asses	1,313	10	0.24
Horses	103	13-15	0.24-0.37
Rabbits and Hares	5	0.01-0.06	0.10-0.21

Agricultural waste: Crops are produced in large quantities for human consumption and exportation, and hence generate a large number of residues. Agricultural crop wastes or residues include rotten crops due to a lack of storage facilities and are caused by infection of diseases and residues generated from crop processing after crop harvest. Stalk, straw, cobs, husk, and bark are crop residues used mainly for energy generation throughout the anaerobic digestion process. The use of crops for building materials and animal feed accounts for 70% of crop residues and after all this, approximately 52 million tonnes were recorded for biogas production from which 21 billion cubic metres of biogas could be produced [51]. Some of the agricultural wastes commonly found are groundnut shells, coconut shells, mango peels, palm oil mill effluent, cherry, orange peels, and melon shells to name a few. The conversion of cassava or its residues to biofuel using an anaerobic digestion process has already been well established in Nigeria, approximately 7.5 million tons of cassava residues are generated annually and 83 million tons of crop residues are generated yearly with an estimated biogas potential of 4.98 billion m^3 [52,45].

Municipal solid waste: Also referred to as household wastes generated from sources where various activities of man are encountered. They include wastes from households, institutions, markets, industries, and human activities. It is heterogeneous and comprises different discarded materials of different compositions. The quantity and composition can be affected by climate, the extent of recycling, collection frequency, regional differences, season, technological changes, and industrial structure [45]. Nigeria has the highest population in Africa with 913,440 tonnes of methane produced from municipal wastes produces electricity equivalent to 482 MW. An increase in population, urbanisation, and industrialisation will increase the amount of municipal solid waste generated annually. The average rate of solid waste generated is approximately 0.50 kg/capita/day [53]. The study revealed that the highest biogas was produced by yam peels (89.37 mL/week) while the lowest biogas was produced by orange peels (18.26 mL/week). The study also revealed the range of mean values of biogas produced for all the food wastes as 32.15–92.43 mL/week while that of all fruit wastes is 18.26–36.20 mL/week [44]. For example, Longjan and Dehouche in their work extracted waste fractions from local Nigeria food processing methods [36]. The food wastes include yam peels, cassava peels, cocoyam peels, plantain peels, corn cob, beans skin, and groundnut shell. The study showed that samples that were used have their methane potential ranging from 35 to 460 m^3/tonnes on fresh weight and volatile solid basis of (5.4–6.2) × 10^5 m^3/kg. The methane potential was also shown to be between 51 and 58% of the biogas generated, while the energy potential of food waste was 31 TWh / year, which can meet the energy demand of Nigerian households of approximately 47 million.

2.10 Renewable policies in Nigeria and the future prospect of medium-scale biogas Plants in Nigeria:

The key documents and projects that the government has embarked on in collaboration with stakeholders are given below:-

- **National Electric Power Implementation Policy 2001:-** Electric power generation was established by the British colonial government in Lagos in 1896, but since the 1960s, there have been constant power outages in Nigeria. The unreliable supply had become widespread and disruptive. In 2000, the National Electric Power Implementation Policy 2001 (NEPIP) was framed. NEPIP portrays the general framework for Nigeria's agenda on sustainable power distribution with a particular focus on efficient distribution and utilisation.
- **National Energy Policy 2003:-** The policy was recommended by the Electric Power Implementation Committee in 2003 to develop Nigeria's energy resources. The NEP of 2003 emphasises the effective use of sustainable energy resources with a focus on solar energy and advocates for the aggressive integration of solar energy in the nation's power supply. It was later reviewed and replaced by the National

Energy Policy 2013, which reemphasised the importance of enforcement and implementation of sustainable energy goals while decrying the failure of implementation, energy loss, inefficiency, and waste in the realisation of such goals.

- **Renewable Energy Master Plan 2005:** The Renewable Energy Master Plan 2005 (REMP) recommends the utilisation of renewable energy and seeks to provide an implementation strategy. It conceptualises Nigeria's renewable energy goals and tries to address the key factors for its attainment. The REMP projects that the minimum electricity demand in Nigeria will be above 315 MW by 2030. The goal is to supply over 20 % of the energy from renewable sources.
- **Renewable Energy Policy Guidelines 2006:-** The Renewable Energy Policy Guidelines 2006 (REPG) is a document by the Federal Ministry of Power that details policy objectives for the development and utilisation of renewable energy. The REPG is similar to the REMP, but a major distinction is that the REPG places more importance on the generation and distribution of renewable energy. It also presents a strategy for a cost-effective administration of the Renewable Electricity Trust Fund. In addition, the REPG provides incentives for the utilisation of renewable energy and recommends a five-year tax break as an incentive for investors in renewable energy in the hopes of encouraging the participation of more stakeholders.
- **Captive Energy Generation Regulations 2008:-** The regulations were issued by the Nigerian Electricity Regulatory Commission (NERC) in 2008 to regulate electricity generation for small or private use. It contains principles similar to those in the general regulations but applies especially to small generators. The CEGR

defines captive power generation as the generation of electricity exceeding 1 MW for consumption by the generator and is consumed by the generator itself and which is not sold to a third party. The CEGR also sets provisions for the licensing and regulation of energy generators used by organizations.

- **National Renewable Energy Efficiency Policy 2013:-** The National Renewable Energy Efficiency Policy 2013 was added by the Federal Ministry of Power to ensure sustainable power generation and strengthen the existing energy laws. It seeks to overcome administrative and social barriers that hinder the sustainable use of energy and improve energy efficiency.
- **National Energy Efficiency Action Plans 2015–2030:-** The National Energy Efficiency Action Plans 2015–2030 (NEEAP) were adopted by the Inter-Ministerial Committee on Renewable Energy and Energy Efficiency and were approved by the National Council on Power. Specific focus is placed on effective energy, emission reduction, efficient lighting, monitoring, distribution and enforcement, and verification of standards of materials, homes, buildings, and industries. It also emphasises the utilisation of local materials and workers, and the establishment of a system for monitoring, verifying, and enforcing minimum energy performance standards and also capacity building.

Some other renewable policies implemented by the Nigerian government are as follows:

1. The Renewable Electricity Action Programme, which was conceived by the Federal Ministry of Power in 2006 and sets out a road map for the sustainable implementation and distribution of renewable electricity in Nigeria with notable targets;

2. The Nigerian Electrification Project aims to increase electricity access for households and micro, small and medium-sized enterprises;
3. The Energising Education Programme seeks to provide educational institutions with sustainable electricity by adopting mini-grid technology, and
4. The Power Sector Recovery Programme 2019 seeks to increase Nigeria's power generation in anticipation of economic prosperity for the nation.

Africa produces and utilises less biogas compared to Europe and Asia, as only a few plants have been built for the anaerobic digestion of feedstock in recent years. The increased utilisation of the abundant waste generated annually from the continent to meet some of the challenges, especially in areas of electricity generation, has a great future with the help of biogas plants for accelerated development. Since energy consumption has skyrocketed, the global energy demand will increase by 50% in 2050 and a surplus will be achieved to counter shortages if biogas plant development occurs. With the formation and enforcement of strong and suitable policies and legislation in a well-regulated economy, a biogas project with the best international design to ensure efficient and effective enforcement that complies with environmental laws will be promoted [54].

3. Aims of the Thesis

The main objective of this study is to identify the effectiveness, economic barriers, limitations, and future prospects of a medium-scale biogas plant in Nigeria for the treatment of organic waste.

The specific aims of this study are:

- To determine the effectiveness of medium-scale biogas plants in the management of organic waste in Nigeria
- Assess future prospects of the use of medium-scale biogas plants in Nigeria for the treatment of organic waste.
- To identify the economic barriers and limitations to the development of medium-scale biogas plants in Nigeria.

4. Methods

The methodology of the bachelor thesis was based on the literature review on "Medium-Scale Biogas Plants: Feasible Solution for Organic Waste Management in Nigeria" according to the information compiled mainly from available online scientific publications in English to obtain the most recent data. The databases like Scopus, ScienceDirect, ResearchGate, SciELO, PubMed, and Web of Science were searched based on keywords such as Biogas Plants of Nigeria, Organic Waste Management, medium-scale biogas plants, biogas surveys of Nigeria.

Search Strategy: A systematic search strategy has been developed to find pertinent literature from electronic databases, including academic journals, conference proceedings, and reliable online repositories, a methodical search technique will be established. The most pertinent articles were found using keyword combinations such as "medium-scale biogas plants", "organic waste management," and "Nigeria." In addition, publications from industry and other sources such as government studies and policy documents were considered.

Data Collection: The identified articles had undergone a two-step screening process. In the initial screening, titles and abstracts were reviewed to assess their relevance to the research topic. In the second screening, full-text articles were assessed based on the inclusion and exclusion criteria. A standardised data extraction form was developed to collect relevant information from selected articles, including author(s), publication year, research objective, methodology, findings, and key implications.

Data Analysis: Data gathered from the chosen articles was analysed using Microsoft Excel 2021 software package (https://softwarekeep.eu/microsoft-office-2021-

home-and-student-pc.html). A systematic summary of the literature review was established according to the extracted data. The investigation will focus on several issues, including the current situation of Nigeria's medium-scale biogas plants, their viability for managing organic waste, the advantages and disadvantages, and the variables that influence their deployment.

5. Conclusions

Biogas technology is not familiar and popular in Nigeria, but there is still some scientific, economic, and engineering-based work in progress and is still being done. The projected future energy available from the digesters ranges from 5 to 171 TJ, but the financial commitment lies in the range of US$72.16-US$1083 million and the annual operating costs lie in the range of US$10.11-US$152 million. The promotional costs and other miscellaneous expenses are extra. The production of organic waste from home and industries will increase in parallel to the population of Nigeria. Therefore, it is also discovered that the amount of biogas produced depends on the amount of organic matter present in the waste produced, and the agro waste material has the highest biogas potential. Biogas provides an alternative solution for recycling organic waste into a form of renewable energy. Biogas operation will bring the cost of electricity to 65% of the total global electricity and will reduce the carbon content by 90% in the air and will also reduce pollution. A comparison between the other renewable sources of energy is also being shown so as to get a statistical idea of the scenario of the outcome of the said sources on the economy. In this study, the idea of the policies employed by the government, cost-effective production of biogas from organic wastes, conversion of biogas for generation of electricity and working of a biogas plant along with its design has been highlighted and shows the importance of employment of a medium-scale biogas plant. Although biogas technology is of immense importance and beneficial for the national economy, some restrictions such as economic, technical and socio-cultural constraints are still some of the barriers that must be overcome for the technology to reach the Nigerian energy market. Some of the recommendations that could be adopted are the introduction of financial incentives such as soft loans and subsidies at the initial stage, coordinated and funded research, development and demonstration of the technology at large scale, educational and campaign programmes, and a well-organised institutional framework for the success of biogas technology in the country. In a nutshell, the use of alternative technologies such as biogas could boom in an environment with a number of factors, such as technology, political will, economics, and personal motivation, which are essential for its adoption and popularisation. Therefore, all these techniques and technologies can be adopted to initiate an enhanced approach to biogas production in Nigeria to address issues of waste management and energy production for the socio-economic benefit of the nation and also the environment.

6. Recommendations

An analysis of the literature reveals that there is a strong possibility of meeting the needs of our rural energy if biogas technology is adopted in Nigeria. The use of biogas technology will not only help us generate electricity for lighting and energy for cooking, but will also help in the treatment of waste which constitutes a major environmental hazard and the slurry from the biogas plants can serve as fertilisers for the farmers. The utilisation of biogas technology cannot be further doubted for its reliability and economic benefit to the nation. The following recommendations are being made for the effectiveness of this process:

1. There should be an institutional framework for renewable energy education in Nigeria and new policies should be implemented to increase the adoption of this technology.
2. An appropriate legal framework should also be adopted.
3. The government at all levels should take an active part in all biogas related projects and increase funding to all research institutes to improve biogas production. For example, India and Nepal also practice this approach.
4. The technical capacity to operate and maintain these plants should also be increased by the government. For example, China implements a training course organised for farmers from time to time to popularise biogas technology and is given a certificate after successful completion of the course.

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