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Techno-Economic Viability of Bioenergy Resources for Sustainable Mini–Grid Power Generation in Southwest Nigeria

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Abstract

Given the lingering inadequate power problems, low clean energy access, and increasing energy cost, Biomass energy presents an opportunity for local energy solutions, especially for rural communities, farms, and agro-allied industries. Comprehensive data on biomass were obtained from various primary and secondary sources, and conservative estimates of the potential of the various bioenergy technologies and power generation technologies in Southwest Nigeria were made. The commercial and technical viability of bioenergy resources was investigated using proven tools such as Techno–Economic Renewable Energy Viability Index (TEREVI), Techno–Economic Levelized Cost of Energy (TELCOE), Levelized Cost of Electricity (LCOE), and HOMER Software simulation Cost of Electricity (COE). Southwest Nigeria is found to have a bioenergy very conservative potential of 3.07 × 10^9 MWh, for non–food Dedicate Energy Crops (DEC); 1.21 X 10^9m3 of biomethane or 6.64 X 10^6MWH, for landfill gas (LFG) Waste – to – Energy (WtE) scheme; 2.1 X 10^9m3 or 21.97 X 10^6MWH of biogas methane. The viability assessment test result using various tools and evaluation models shows very highly competitive techno-economic feasibility of bioenergy technologies for sustainable commercial-scale off-grid distributed power generation in Southwest Nigeria with competitive indices of $0.014651/KWH TELCOE, 0.791839506 TEREVI, $0.014077/KWH LCOE, MATLAB Simulink value of $0.01862/kWh, and a HOMER COE value of $0.0127/KWH. The overall funding reveals that biomass is a great energy prospect for power generation in southwest Nigeria with a high score of 0.791 given a regional potential of 3.07X10^9MWH, for non – food Dedicate Energy Crops (DEC); 1.21 X $10^9$$m^3$ of biomethane or 6.64 X 10^6MWH, for landfill gas WtE scheme; 2.1 X 10^9m3 or 21.97 X 10^6MWH of biogas methane, for animal wastes and so on.

Keywords: bioenergy, biomass, biogas, biopower, landfill gas, MSW, Waste–to–Energy (WTE), non–food Dedicated Energy Crop, biomethane, biofuel, biodiesel, bioreactor, TEREVI, TELCOE, LCOE

1.0. Introduction

Despite over $20billion worth of investment by the Federal government over the years, power generation from the national grid has virtually remained the same in 25years and hovering between 3,000MW and 4,000MW resulting in Ease of Doing Business Difficulties, high cost of production, unemployment, de-industrialization, and insecurity among other direct and indirect consequences (Cole, 2019; Akpan et al, 2023).

Following the gross inefficiencies of over 30% line loss being suffered by the 8,000MW national grid couples with lack of redundancies resulting about 10 collapses per annum especially in the last 10years, it is now a dire need to diversify power generation and distribution by prioritizing renewable and hybrid energy driven mini – grids and distributed generation to harness locally available energy resources and cutting losses(Akpan et al, 2023; Arogie and Odoh, 2022; Okwori, 2011).

As an agrarian region, over 35% of persons in Southwest Nigeria work in agro – allied industries while about 50% of the population reside in rural areas where lot of renewable energy resources like small hydro, biomass, and so on are readily available and more easily harnessed with minimal socioeconomic impact considering that agriculture accounts for about 30% of the nation's Gross Domestic Product aside the added advantage of geographically evening infrastructural development, engendering value-added agriculture, enhancing food production, growing cottage industries, and mitigating rural – urban migration(Aderemi, 2017; FAO, 2020).

This study on the Techno-Economic Viability of Bioenergy Resources for Power Generation in Southwest Nigeria is a necessity as the population keeps growing with the hydra–headed consequences of energy poverty, import dependence, and spiralling foreign exchange rates becoming intractable and perniciously dangerous in all facets of national life. Biomass accounts for over 70% of energy consumption in Nigeria, like in the rest of Sub-Saharan Africa, and is usually applied quite inefficiently with lots of inefficiencies, environmental pollution causing health hazards, deforestation, and non-utilization for electricity generation among other things (Ben–Iwo, 2016; Okafor et al, 2022).

A conscious adoption and development of the various bioenergy resources available in the region for power generation especially via Waste – to – Energy (WtE), Landfill Gas (LFG), Biogas, and Dedicated Energy Crop (DEC) biofuels. This is particularly instructive given the rising prices of gas, forcing many small businesses and individuals in urban areas to switch from gas to coal, sawdust, or other forms of biogas. Given the vast bioenergy potentials of Southwest Nigeria, biomass power generation, especially in rural and peri–urban areas and farm settlements as well as in the utilization of LFG and WtE in highly populated urban and industrial areas, is a very strategic action towards a sustainable, clean, and renewable energy solution.

This research is based on the urgent imperatives for creative approaches to solving power problems by taking off one community at a time from energy poverty using clean, affordable, and locally available renewable energy resources for power generation via networks of bio-powered mini–grids with rural, peri-urban, and exclusive urban communities as focus. Bioenergy resource utilization by this study is found to be one of the cardinal alternatives to energy security in Nigeria, being the default energy source for locales in Sub-Saharan Africa, and being the fallback option for energy needs, but for power generation.

With the climate change challenges of coal-fired power generation concerning financing and international governance legislative alienation, wood biomass and municipal solid waste conversion technology is a great opportunity for Southwest Nigeria and Sub-Saharan Africa to develop small and medium grid interoperable biopower plants.

1.1. Objectives

1.1.1. Acquire the bioenergy data of Southwest Nigeria
1.1.2. Estimate Bioenergy Potentials in Southwest Nigeria
1.1.3. Design a hypothetical bioenergy-driven mini-grid in a hybrid configuration
1.1.4. Simulate and assess the techno-economic viability of bioenergy power generation in Southwest Nigeria

2.0. Literature Review

Okafor et al (2022) assessed the biomass energy situation in Nigeria based on a wide pool of research surveys by unravelling the drivers and challenges of biomass energy development in Nigeria. The research shows that 50% of Nigeria's landfills are biodegradable, and the country's municipal solid waste (MSW) generation is expected to grow by 50% between 2020 and 2040. Their finding further reveals that while biomass consumption is driven by the need to manage mounting environmental waste, energy transition, energy cost, and economic exigencies, effective development of high-exergy biomass energy conversion systems is limited by inadequate regulatory policy, technological disadvantage, poor enlightenment, and lack of political support.

Elehinafe et al (2021) identified and analysed wood biomass and its products concerning biomass-fired steam turbine power generation in Southwest Nigeria. While the result shows good thermal analysis, long–term sustainability was not addressed, in addition to the study being steeped in the technicalities of thermal generation. This leaves a wide gap of uncertainties for adequately comprehensive multicriteria factors governing successful bioenergy applications.

Greeneneergyinsight (2024) reported on the two noted bioenergy facilities in Nigeria, notably, the Okababa Biomass Power Plant in Lagos and the Zungeru Biomass Power Plant in Niger State. In the report, the success and continued operation of the plants are hinged on the stable and adequate supply of biomass feedstock. Posibi (2023) carried out an overview of biomass power generation potentials in Nigeria based on farm waste, industrial waste, and municipal solid waste for gasifiers and diesel generators, among other technologies. The studies show that the bioenergy conversion process suffers from massive inefficiency due to poor technology and unsustainable development.

Jekayinfa et al (2020) in their studies concluded that biomass energy systems are best developed in Nigeria when the agricultural industry, as well as the agro-processing sector, are well developed in order to create a more

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comprehensive and sustainable circular economic structure. Ogunrewo and Nwulu (2024) carried out studies to optimize the operational logistics of the biomass energy value chain, given the high sensitivity of transportation, supply efficiency, and logistics cost on the viability and competitiveness of biomass energy. However, the study did not take into consideration all the types of biomass energy sources and technologies.

3.0. Biomass Power Theories and Methods

Tables 3.1, 3.2, 3.3, and 3.4 show the bioenergy information for various types of biomass energy conversion systems, such as biofuel, biomass, and MSW for power generation, based on conservative records and projections as stated in this study. Figures 3.1, 3.2, 3.3, and 3.4 show the study workflow diagram, a hypothetical mini-grid power system design schematic for the biomass system, the bottom-up mini-grid concatenated network, and the bioenergy powertrain respectively.

Biomass power is electricity produced from the chemical energy in the remains of recently living plants and animals through thermal decomposition for direct heat, liquid fuel extraction, or the liberation of energy gas for power generation. Therefore, the difference between fossil fuel and biomass is the fact that the former takes eons to occur while the latter takes place in a matter of days, weeks, or a few years at most.

Mostly in form of wood, coal, sawdust, and plant residue, Nigeria has an estimated biomass potential of about 144MMTPA (Shaaban, 2013) and is the main source of energy in rural and peri – urban communities; making up around 80% of the country's primary energy use(Ben – Iwo, 2016; EIA, 2015) and as well the key fallback source in times of high gas prices in even urban communities both for small businesses and individuals by which a 2022 survey by the Nigerian Bureau of Statistics revealed about 70% of Nigerian homes still consume biomass especially in form or wood and coal (Ajala, 2022) following which the World Health Organization reported annual death rate of 93,300 from kitchen smokes in Nigeria worsened by the fact that 174million people lack access to domestic cooking gas called liquefied petroleum gas (LPG) (Ajala, 2022) due mainly to high prices, low income, cost of cylinders, infrastructural deficit and low gas penetration rate(Olayinka, 2021).

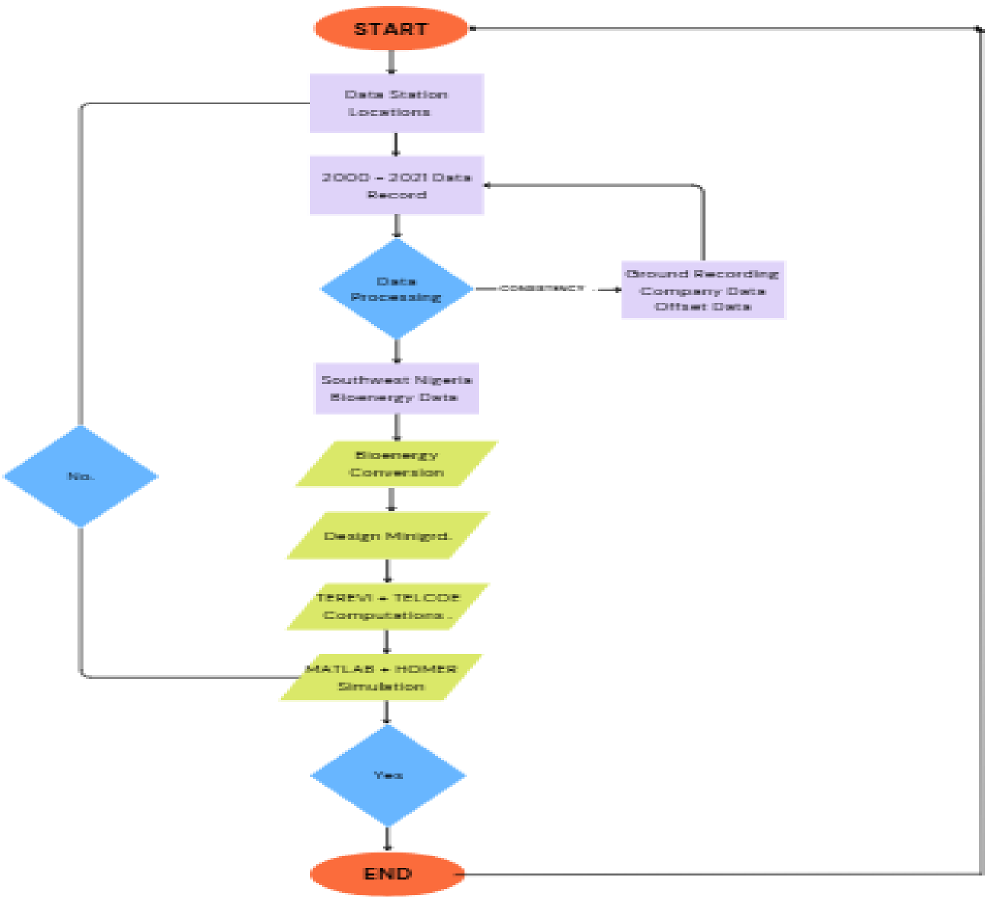

Figure 3.1: Bioenergy techno-economic viability workflow.

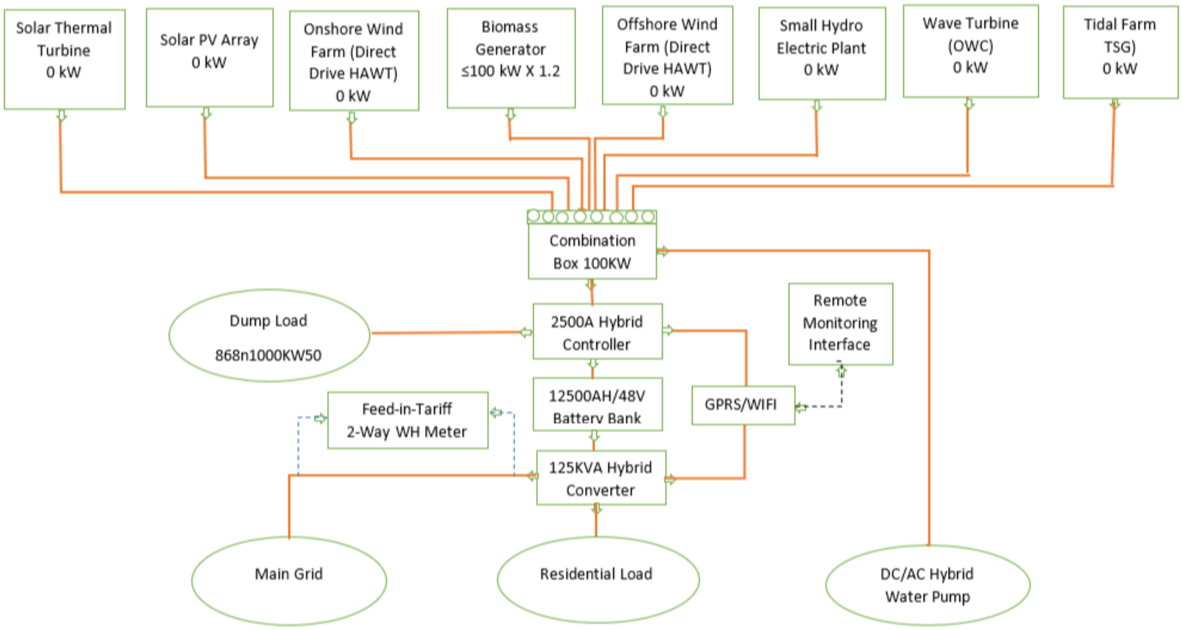

Figure 3.2: Biomass hybrid hypothetical power systems schematic

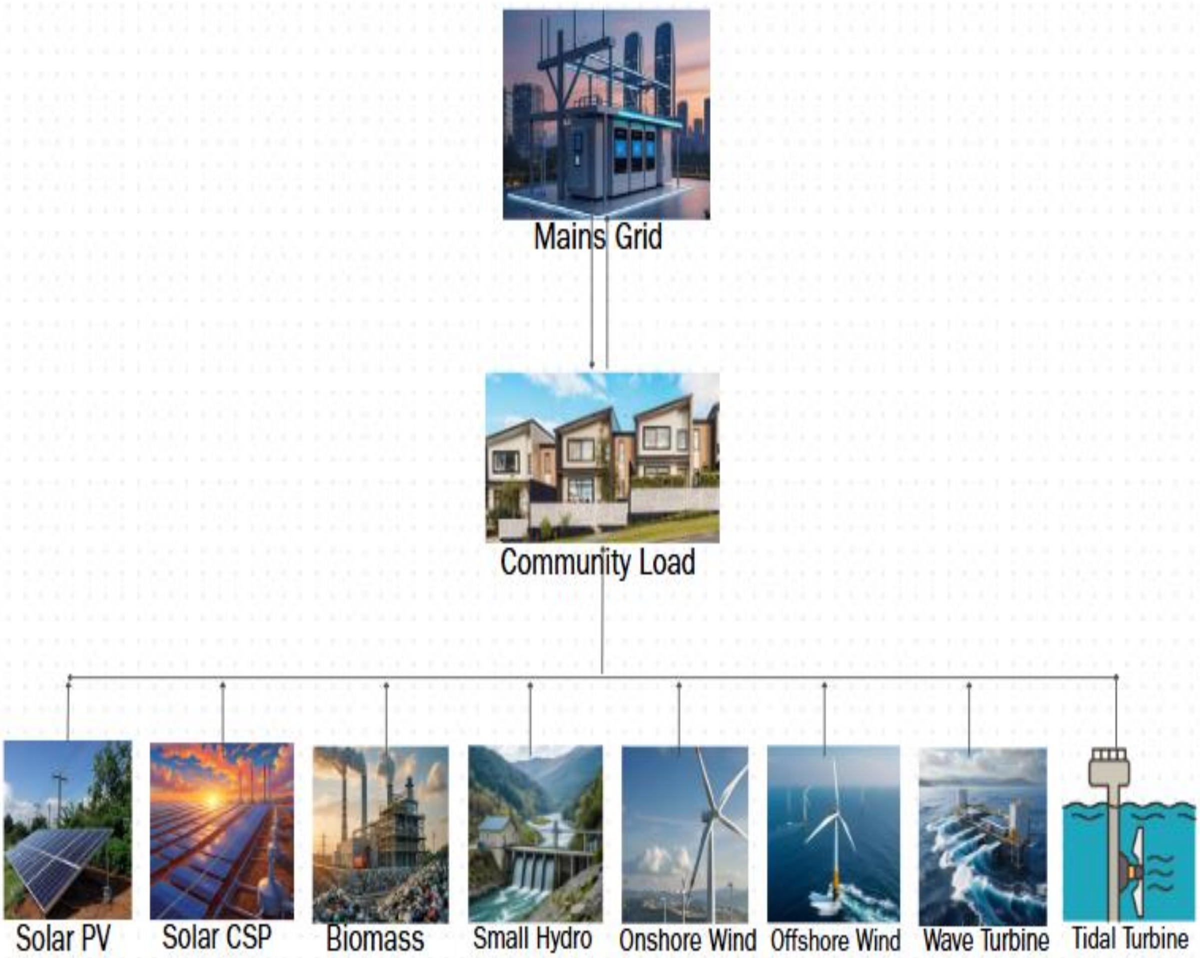

Figure 3.3: Bottom hybrid mini-grid power generation in concatenated networks

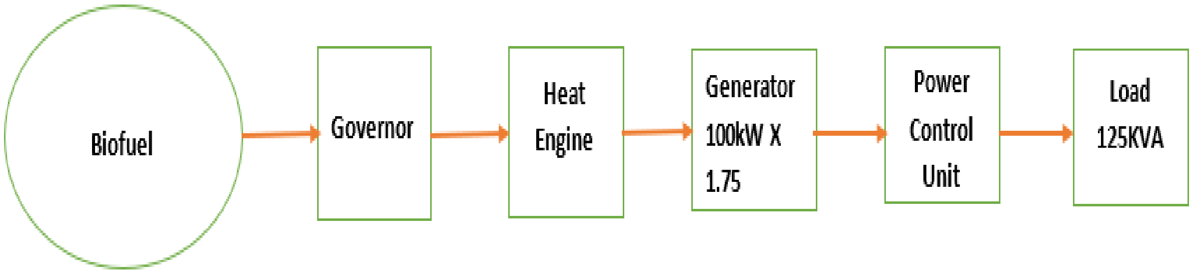

Figure 3.4: biomass system powertrain

Biomass, mostly plant residue, coal, wood and manure are responsible for around 80% of primary energy consumption in Nigeria. Biomass consumption can be improved by co – processing non – food biomass with conventional petroleum facilities (Ben – Iwo, 2016) like refineries and gas production plants for blending and ancillary uses.

Fossil fuel for road transportation is the leading source of GHG emission at about 23% globally(Saboori et al, 2014; Andres et al 2012) and around 60% in Nigeria(Tajudeen, 2015) with a premium motor spirit(PMS) and automotive gas oil(AGO) emitting 0.0089MTCO2/gallon and 0.0102MTCO2/gallon respectively(Annamalai, 2013) which can be mitigated with ethanol(Larsen and Troels, 2009) from renewable sources either as fuel blend or as standalone fuel.

Nigeria has 71,000,000Ha of agricultural land of which over 37% are arable with 33% pasture and meadow areas, 7% permanent crops, and about 10% being forest land (FA), 2016) while unfortunately Nigeria suffers a deforestation rate of 1200Km^2 per annum (Mohammed et al, 2013).

Biofuel could be gaseous (such as biogas, landfill gas, syngas and mash gas), liquid (biodiesel, bioethanol and so on) or solid (wood and coal) with combustion efficiencies being highest for gaseous fuels and least for solid fuels. Hence the emphasis on gas as the cleanest and most environmentally friendly of them.

Biodiesel is produced from soybean, linseed and other oily food via crop harvest, oil extraction, transesterification of the oil and finally 2 – stage distillation while bioethanol while bioethanol is produced from starchy or carbohydrate crops via crop harvest, milling and grinding, liquefaction, saccharification, fermentation, and finally distillation for fuel recovery.

The FGN in 2005 mandated the state oil company, Nigerian National Petroleum Company (NNPC) to ensure 10% biofuel blend of all its liquid petroleum products (NNPC, 2007). To this end, the NNPC acquired swaths of arable lands across the country for its automotive biofuel programs with sugarcane, sweet potato, corn and cassava selected (NNPC, 2007) as dedicated energy crops (DEC) prompting the company to project Nigeria saving €110million from biofuel production (Kupolokun, 2006).

Jatropha is a non – food DEC with the combined advantage of longevity of up to 50years with 6monthly harvest, ability to thrive in low fertility soil as well as all vegetations in Nigeria due to its low nutrient and water (Abila, 2010) requirement asides being a means of controlling desert encroachment, farm hedging and livestock feed production from its seed remains after oil extraction. Research shows that the Jatropha plant is a proven means of soil remediation from the devastating effects of heavy metal and petroleum production (Kumar et al, 2008), thus seriously being considered for environmental cleanup.

Apart from Jatropha, water hyacinth and other wild weeds such as Anthropogony, Hyparrhenia, Pennisetum, Paspalum, Panicum, Chloris, and Melinis among others, most DEC especially food DEC cost more energy to produce than the value of energy they produce, which is a big challenge for private sector initiative without active government support or strong political will hence automotive biofuel projects such as : the National Cassakero $1billion 8MMTPA cassava plantation; the NNPC 1.268billion 16.7MMTPA sugarcane and cassava plantation with strategic sites at Benue(Agasha, Guma and Bukaru), Gombe (Kupto) and Abuja(Kwali), Anambara(Ebenebe) and Ondo (Okeluse) ; the Global Fuel $152million 2.0MMTPA sweet sorghum plantation located at Ondo State (Arigidi and Akoko) and Ekiti State (Illemso); the Ethanig/Starcrest Energy $600million 6.5MMTPA sugarcane located at Benue (Kastina Ala and River Benue) and Kebbi; the Savannah Sugar $167million 1MMTPA sugarcane plantation located at Adamawa State (Numan); the Kwara Complex $90million 0.3MMTPA cassava plantation at Kwara; the Ekiti State Government $18million 0.24MMTPA cassava plantation at Oke Ayedun; the Crownet Energy/Ekiti State Government $122million 0.15MMTPA cassava plantation at Ekiti (Iyemero); the Taraba State

$115million 0.3MMTPA Cassava plantation ; the Niger State $90million 0.15MMTPA cassava plantation; the Niger Delta $138million 0.32MMTPA cassava plantation; Niger Delta $85million 0.857MMTPA sugarcane plantation; and the Ogun State Government PPP $16.4million 0.075MMTPA cassava bioethanol projects (Ohimain, 2010) all yet to make a headway despite the humongous investments.

The volume and quality of Municipal Solid Waste (MSW) production typically increase with industrialization, quality of life, economic status and predominant activities in a given geographical location (Sowunmi, 2019; Duku et al, 2011; Ogwueleka, 2009). Hence, upscale neighborhoods tend to generate more MSW per head than downtown and shanti districts.

In the handling of municipal solid waste, sustainability is the primary drive, which means the number one priority is the minimization of waste generation, while efficient and economically viable recycling is preferred, and more economically viable to processing for power generation depending on technoeconomic variables taken into consideration even though power generation is a step before final disposal or repurposing. The basic workflow of integrated waste management is: Reduction, Reuse, Recycle, Recovery (power generation) and Disposal (IEA, 2003).

MSW to power generation actually reduces carbon emission given that it is made up of about 30% fossil fuel derivative products like plastics, nylon and so on, which makes it 220Kg of fossil of the 1100Kg CO_2 emitted per ton which when compared to the 592Kg emitted by 1ton of coal combustion and 1610Kg emission of non – utilized landfill making a net carbon emission of – 1982Kg knowing every electricity power generation source necessarily emits carbon but emphasis is on minimization to acceptable levels including noxious dioxins, furans and so on (IEA, 2003).

The conversion of chemical energy of biomass to heat and power is based on either biochemical or thermochemical process. The biochemical process is the aerobic or anaerobic decomposition(digestion) of organic matters as in bioreactors, landfills, and biodigesters while thermochemical process is the thermal decomposition or combustion of organic matters in the presence or absence of air such as incineration and pyrolysis. While biochemical process of energy conversion is cheap and does not require heat, it is very slow and of relatively longer lead. Thermochemical process is fast, absorbs heat, reduces the volume of waste though more environmentally hazardous.

Hence, biomass electric power generation technologies vary a great deal with biomass source but generally based on same principles as fossil fuel energy conversion systems and includes the following methods:

a. municipal solid waste (MSW) combustion for steam turbine power generation also called Waste – to – Energy (WtE): based on the fact that generally over 60% of municipal solid wastes in South – West Nigeria are thermally combustible based on results of various studies with energy values of about 30% of same weight of coal, between 8Mj/Kg and 12MJ/Kg or around 0.6MW of electricity (IEA, 2003) with 0.45J/Kg and 2.2Kg(UN Data, 2012) per capita waste generation globally which typically increase with economic advancement. Hence, once non-combustibles are separated for repurposing, the MSW is hauled into incinerators where the heat generated is used to boil steam, which in turn runs a steam turbine for electricity generation (EPA, 2022).
WtE technologies are based on various technoeconomically feasible combustion methods for optimizing energy conversion to power or heating purposes, which are divided into 3 types: Incineration, that is controlled combustion or burning of MSW; pyrolysis, that is combustion in the presence of little or no air; and gasification. While circulating fluidized bed gasification and pyrolysis (low temperature torrefaction) may have higher efficiencies, incineration remains the most basic and widespread WtE technology due to relative cost and technical complexities, subject to ongoing research and development efforts (Kokali, 2013; Ibikunle, 2022).
The solid particulates left after combustion are primarily ashes and make up 15% to 25% of the total weight of MSW combusted. The ashes of two types; fly ash and bottom ashes which could be repurposed for several application such as agriculture and construction materials among other things.
The energy value of MSW varies with location, economies and lifestyles generally and tends to be higher in quantity and quality in more developed areas of a country or in more advanced countries of the world due largely to more advanced waste management and separation.
Due to low output electricity power efficiency around 23% compared to other fossil sources , the efficiency of MSW to energy conversion should be greater than 65% to be regarded as a heat energy recovery system else it will be classified as mere waste disposal(European Commission, 2008) as most plants are design around 70% given the temperature of superheated steams that are typically in excess of 300◦C with about 60◦C condensation temperature(Kokali, 2013).

The quantitative measurement of MSW output Q_{MSW} in the South – West is carried out by multiplying the total collected volume Q_{cMSW} by 1.25 knowing that only about 75% of municipal solid wastes are collected for disposal in developing nations (Ogunjuyigbe, 2017) such as Nigeria and the rest of Sub Sharan Africa.
For technoeconomically feasible WtE system for power generation, the MSW should have a minimum LHV of 7MJ/Kg, and 80% of MSW in Southwest Nigeria is thermally combustible (Olayiwola et al, 2019).

	Combustion Properties			
Component Materials	Moisture	Ash	Combustibles	Heating value
combustible fraction		(%)		(MJ/kg)
Textile	7.6	5.8	86.7	16.7
chart board	6.9	11.9	81.3	17.5
soft paper	24	12.4	63.6	10.1
plastic foil	0.5	13.2	86.3	40.1
hard foil	0.4	5.3	94.3	40.1
PET bottles	0.4	0.2	99.4	21.5
Wood	12.5	2.3	85.2	16.3
Styrofoam	1.1	10	89	28

Table 3.1: Average composition of MSW in Southwest Nigeria (Source: Kokali, 2013*)*

The loss factor is the fraction of energy loss due to particulates of combustion as well as thermal radiation and is typically about 0.98 for a well-designed and operated plant.

a. Wood chips, briquettes and coal gasification to power via biomass generator:
Biomass generator simply means a conventional generator that is fired by gaseous, liquid or solid fuel obtained from the biological, biochemical or thermochemical decomposition of biomass resources. The power output value varies with various sources of biomass including wood type, sludge type, crop type etc.

Biomass generators come in various design, capacities and biomass type including the biodiesel generator which uses biofuel extracted from plants like jatropha or processed from castor oil, linseed oil, palm oil, groundnut oil, corn oil and so on. Similarly, the bioethanol generator just uses ethanol just like a petrol engine for power generator. The biogas generator uses energy gases liberated from organic matters during bio-digestion, pyrolysis and gasification.

Sludge biomass generators works just like the solid biomass generator but has a drier unit to first desiccate the sludge after which it is gasified into methane and other components of products before undergoing cooling and filtration prior to being fed into the engine.

A biomass gas generator works like just the normal diesel or gas fired generator except that it used solid fuel in form of wood chips, briquettes, coal, sawdust etc. the solid biomass are loaded on a the generators hopper which get drawn into it gasification chamber from which the syngas and other energy gas produced are channeled to the cylinder inlet and normal 4 – stroke reciprocatory piston engine combustion cycle is achieved for power generation with solid residues as main byproducts which are also used for agricultural landfilling among other possible uses.

The key components of the biomass gas generator are: the gasifier, cooling/ filter unit, internal combustion(gas) engine, and alternator (generator). The gasifier thermochemically breaks the biomass into gaseous, liquid and solid fraction by which the gaseous fraction primarily energy gas called syngas is directed to the engine.

Biogas generator are broadly classified as Biogas and Biogas – Diesel (Mixed Burning) Plant. Small Biogas Plant (SBP) range in capacities from 0 – 50KW, Medium Biogas Plant (MBP) range in capacities between 50Kw and 500Kw while Big Biogas Plant (BBP) have capacity above 500KW (Dayang, 2023).

Biogas power generation system is made up of : biodigester, gas – water separator unit, treatment unit (desulphurization), decarbonization unit(carbon dioxide removal), gas storage unit(tanks), voltage stabilization tank and electric power generator plant set(engine and alternator), heat recovery unit(for combined heat and power solution(CHP)), and control module (adjustment of output variables, transmission and distribution).

Due to the proximity to fuel source, byproducts, dusts, type of fuel and considerably higher noise, fumes, biomass generators are mostly fitting for rural and agricultural electrification as a far more efficient and cleaner way of biomass energy conversion compared to incineration. Hence it provides an optimal means of utilizing wood and plant wastes especially from the preparation of construction and agricultural lands among other things which lends credence to its viability for mini – grid power generation due to their rurally suitability.

Biomass has just same types of fuel as fossil such as gas, liquid and solid but obtained from 4 main sources: wood and wood waste; agricultural crops; biogenic materials (organic wastes from MSW); and animal manure.

The energy from biomass generally is obtained from: Direct combustion for heating, thermochemical decomposition to gaseous, liquid, and solid biofuels, and biochemical processing to liquid biofuels (EIA, 2021).

Biological conversion to produce liquid and gaseous fuels. The gases are obtained from biogas digesters, pyrolysis (350C to 500C), gasification (750 – 950C); and hydrotreating, processing bio – oils at elevated temperatures with hydrogen in the presence of catalysts to produce biodiesels.

b. Fueling power generators using biodiesel extracted from oily dedicated energy crops such as jatropha, linseed, palm nut, groundnut, castor seed and so on:

As global energy use continues to rise from 5.24 × 1017 Btu as of 2010 to a project 8.2 × 1017 Btu by 2040 especially due to falling global hydrocarbon reserves (Bilgen, 2014), biofuels especially from crop cultivation have continued to top the list of alternative fuel sources being strongly advocated to help achieve the Net Zero 2050 goals (Navar, 2018). However, the challenge of crop cultivation for energy verses crop cultivation has generated strong public because it induces famine and hence generates outcry due to poverty in developing countries with millions starving globally since food crop and energy crops are mutually exclusive in cultivation.

Hence, there is a need to avoid both space and supply competition between food and energy. Thus, for thus study, we shall be focusing on non – food dedicated energy crop (DED) such as Jatropha *Curcas*, Moringa *Oleifera*, and Croton *megalocarpus*.

Jatropha Curcas plant produces non – edible oil that is pressed out of its seed. The seed oil content ranges from 30% to 50% by weight. The oil has high free fatty acid (FFA) content of 14% which is way above the maximum of 1% required for transesterification of bio – oils to biodiesel(Pramanik, 2003; Tawari, 2007); thus it only needs to be diluted with some amount of conventional diesel to reduce its viscosity for use in firing generators, although it may still be used directly since its quality is equivalent to that of standard biodiesels that have undergone transesterification(Tawari, 2007).

Jatropha Curcas as a non – food crop like Moringa Oleifera and Croton megalocarpus do not compete with food crop in terms of agricultural land as they are easily intercropable with food crop as well as can be planted on marginal land and to hedge farm lands. Jatropha needs just 20mm of rainfall which means they can survive on semi-arid lands and grow primarily in tropical and sub-tropical climate zones (Navar, 2018).

The biofuel cultivation potential is based on Jatropha being the most technoeconomic biofuel crop for energy production that does not compete with food or cash crop land and can grow both in the wild and in less fancy lands and in semi-arid zones just like weeds and needing little or no post extraction process for use in fueling electric power generators.

Jatropha Curcas starts yielding with 15months of planting with annual production of 338,800Litres per square kilometers annually (Addison, 2001) or 7Tonnes per hectare and of density between 0.86 and 0.92g/cm3, cetane number of 23 to 51, energy value of 39,628 MJ/Kg and ignition temperature of 340◦C. (Jatropha Knowledge, 2023).

The yield gets better with more soil nutrients and alkalinity, with lifespans well up to 40years and over. Up to 2,500 trees with an ideal spacing of 2m X 2m per hectare is optimal. Jatropha has a carbon emission reduction (CER) of 940MTCO2E/Km2(Jatropha Knowledge, 2023). The table for biodiesel/plant biomass potential for Southwest Nigeria, based on a 5% conservatively assumed marginal land area for non–food biofuel plant cultivation, is given as follows:

State/City	Biofuel Land (HA)	Oil Yield (Ltr/Ha)	Oil Yield (MT)	Energy Value (MJ)	MWH
Lagos	1672.5	3164370	11707.5	4.63945E+11	128873568.6
Ogun	8381	15856852	58667	2.32486E+12	645793350.6
Oyo	14227	26917484	99589	3.94651E+12	1096253669
Ondo	7750	14663000	54250	2.14982E+12	597171992.2
Osun	4625.5	8751446	32378.5	1.2831E+12	356415361.3
Ekiti	3176.5	6009938	22235.5	8.81148E+11	244763462.4
Total	39832.5	75363090	278827.5	1.10494E+13	3069271404

Table 3.2: Biofuel Energy Potential of Non–Food DEC in Southwest Nigeria

Hence, cultivating non–food energy crops like Jatropha Curcas and Moringa Oleifera in particular, using vast marginal lands such as mashes, fallowed lands, hedges, and so on, is a very viable way of generating energy for fueling electric power generators for mini-grids and distributed generations in the region.

Bioethanol generators are power generators fired from bioethanol obtained from the processed liquid extracts from carbohydrate–based dedicated energy crops such as sugarcane, sorghum, maize, cassava, linseed, and so on, as described earlier here.

c. Fueling gas generators or turbines using landfill gas (obtained from organic remains at dumpsites).

Landfill gas (LFG) is gas liberated from organic matter as it undergoes degradation on a dumpsite. Due to submergence by layers of waste, these liberated gases, made up mostly of methane, migrate downwards and get trapped under the landfills, while a part of them diffuse from the landfills into the atmosphere.

Non – engineered landfills are open, non-designed, and unplanned areas of land used for dumping of MSW and other wastes, and typically it takes years to well over a decade or more for the dumpsite to start having ample LFG volumes trapped due to uncontrolled migration of leachates and liberated gas.

An engineered landfill, is an area of land that is properly planned, excavated and lined with materials that enable quicker liberation and control of LFG and leachate (contaminated water) migration and trapping beneath landfill within a short time (3years) for easy collection, treatment and use for power generation, organic fertilizer production and avoidance of underground water pollution.

LFG production from dump to methane liberation is based on the 6 mechanism of long-term settlement as stated by Yen and Scalon in 1975 in the following order: Movement of fines into large voids; Strength loss due to chemical & biological reactions; Material loss due to biodegradation and methane production; Creep processes; and Consolidation processes (Eastes and Datta, 2015) which are in corroboration of Sowers' 5 mechanism finding of 1973: Mechanical: distortion, bending and crushing; raveling: erosion, sifting of fines; Physico-chemical: corrosion, oxidation and combustion; Bio-chemical decay: fermentation & decay, aerobic and anaerobic; Interactions, between the four other mechanisms(Eastes and Datta, 2015).

According to Yuen et al (1994), 60% minimum moisture content, methanogenic PH value of 6 to 8, and methanogenic temperature of 34C to 40C are optimum conditions for LFG production and conditions should be maintained within these range for best harvest of methane gas from dumpsites whether on engineered or non – engineered landfills.

Similar to biogas from digesters. landfill gases are typically composed of 45% to 60% of methane (EPA, 2022; ATSDR, 2001) but vary greatly depending on the quality of waste, type of organic matters primarily disposed on the landfill, climatic conditions and soil conditions as well as the age and nature of the landfill area among other factors.

Between 40% to 75% of MSW on disposed at landfill also called dumpsites are biodegradable and similar to biogas undergo the 4 processes of methane liberation: Hydrolysis, Acidogenesis(fermentation), Acetogenesis and Methanogenesis (Eastes and Datta, 2015).

Though it varies primarily with waste composition and several factors, between 100Nm^3 and over 150Nm^3 of methane and around 550KWh of Refuse Derived Fuel (RDF) for WtE plant worth of energy is produced per metric ton of MSW (Zhao, 2019; EPA, 2022).

Aside from Lagos and Ogun, the average composition of waste sources from the major waste generation cities includes: domestic, 76.42%; commercial, 14.37%; agricultural, 5.39%; and industrial, 3.76% (Olubanjo, 2019).

Oyo State MSW 2012 – 2015 = 2,411,145.78 (Moruf et al, 2020) = 602,786.445TPA. drawing inference from several literatures and government records, as well as waste management progress, only about 25% of waste generated from Oyo State is on official figure quoted by the Oyo State Waste Management Agency (OYOWMA) which is similar to that by most non – industrialized states in the Southwest as primarily the capital cities and to some extent the major towns are given some marginal levels of waste management attention by governments at various levels that may be in charge. Hence for states without waste generation data for the entire state, the value is estimated by a multiplier of 1.75 while for state with credible data for the entire state, the values are left intact with respect to national annual population growth rate of 2.5%.

With a 2022 population of Lagos state, the foremost state in Southwest Nigeria and the 4th largest economy in Africa generates over 14,000MTPD of MSW of which 70% are properly collected and disposed in designated landfills while 30% are being dumped in drainages, lagoons, open land spaces and other unauthorized locations (Bello, 2021).

The Lagos Waste Management Authority (LAWMA) has engaged the services over 837 PSP (waste collector companies called private sector participation scheme) with combined manpower of 8,200 employees so far and have in the last 4years created some 30,000 jobs with a potential addition of 6,000 more jobs for recycling including street captains and waste policing agents to enhance the Cleaner Lagos initiative by the State Government (Bello, 2021).

The estimated 2023 population growth in Southwest Nigeria, based on a national 2.5% growth rate and the 2006 National Population Census, is given for all the states in Southwest Nigeria, as well as 5% conservatively assumed marginal land area for non–food biofuel plant cultivation.

Based on Abila and Kantola (2013), Bello (2021), Suleiman et al (2021), Rominiyi (2018), Fadipe et al (2011), Olanrewaju and Ilemobade (2009), and several subjective surveys and interviews, the estimated WtE potentials and MSW metrics for Southwest Nigeria are stated in the following table.

Energy to Waste Potential of Southwest Nigeria							
S/N	State	Population 2023	Land Area (Km^2)	MSW(MTPA)	RDF WtE (MWh)	LFG Potential (Nm^3)	LFG Power (MW)
1	Lagos	13867428	3,345	5040000	2772000	504000000	532207
2	Ogun	5707803	16,762	5549995.75	3052497.663	554999575	586060.8
3	Oyo	8491990	28,454	1285264.315	706895.3733	128526431.5	135719.6
4	Ondo	5266134	15,500	199712.3968	109841.8182	19971239.68	21088.95
5	Osun	5199307	9,251	4941.336722	2717.735197	494133.6722	521.7885
6	Ekiti	3650297	6,353	213.8361522	117.6098837	21383.61522	22.58038
	Total	42182959	79,665	12080127.63	6644070.199	1208012763	1275621

Table 3.3: Landfill Gas Power Potential of Southwest Nigeria

d. Fueling generators or turbines with biogas (obtained from the anaerobic digestion of organic matters).
Biogas is a mixture of gases primarily composed of methane that is liberated during the anaerobic digestion(decomposition) of organic matters by microbes under given thermophysical conditions. Also called bioreactors, biogas digesters are oxygen free enclosures that are used to breakdown(digest) organic matters such as food, plant and animal remains as well as animal wastes by the activities of anaerobic bacterials in a series of

processes called thermogenesis, hydrogenesis, acetogenesis and methanogenesis resulting in the production of energy gases primarily methane(CH_4), effluents (liquid organic fertilizer) and semi-solid substrate (semi-solid fertilizer) Common biogas feedstocks include : cattle dungs, pig slurry, bird dropping, compost, and food wastes which all vary in their energy values (Methane volume).

Biogas digesters are simply any form of containment whether built in bricks or as plastic tanks or even metallic tanks with valved or closable openings for injecting and draining influents (fresh feeds) and effluents (digested mixtures) respectively. Digester designs could be underground or above ground containment and could be made of brick, tanks or flexible bag systems etc.

Underground containment are usually built by digging cylindrical holes slightly above the sized of the digester volume and lining it accordingly with burnt solid bricks with domed top design like a mosque using high quality cementing and metallic props.

A biodigester usually has 3 valved opening or pipe connections to it. The first drainage line or pipework (typically 4inch or larger) is called the influent pipe and leads from the mixing chamber on the surface to the digester so that new feeds can easily be mixed and fed into the digester. If it simply a hole, there must be cover. If it's a pipe it must have valve which gets locked immediately feed injection is complete.

The second pipework is called the effluent pipe or discharge pipe (typically 3inch and larger) that is normally closed but only opened during effluent discharge. The third pipe is the gas line linking the gas cap of the digester and is also valved and may have a pressure gauge installed on it for gas pressure/production reading.

The gas line is for collecting the biogas generated and linking to use (kitchen, burners, tanks, or treatment system) and is suspended from the top of the dome or near the top without coming in contact with the digester liquids. The gas cap or gas hold is the digesters ullage (empty space not covered by the liquid inside the digester).

The same principle and number of pipework (external connections) on the tanks applies for all types of design and materials, both surface and underground. Sometimes, domestic water supply tanks (preferably plastic) could improvised with side tap for effluent collection, topside injection pipe for influent injection and top pipe for gas collection to use.

Due to the corrosive nature of hydrogen sulphide, carbonic acid and other aggressive chemical in the biogas and digestate fluids, metallic tanks are often avoided both for the digester and gas storage.

A given feedstock type, the volume of gas produced is determined by the stirring rate, heating rate and total solid matter to water ratio before feed. Waste from animal such as cow dung is first dried and where possible grounded (to increase surface area of reaction) and mixed with water in 1:1 ratio. The mixture is stirred continuously up to homogeneous sludge condition before being injected into the biodigester.

The better the stirring, the higher will be the gas production level and stirring may be continuous even inside the digester. Without stirring gas will still be produced but significantly less than if stirred. Hence, most commercial digesters have motorized helical stirrer installed to optimize the digestion process.

Heating is very important in order to improve thermophilic conditions with optimal temperatures around 40◦C. thus warming the digester mixture improves biogas production. Hence, commercial digesters have systems for periodic warming especially in non – tropic zones which could be from hot water or system or possibly electric coiled heating.

Also called Hydraulic Residence Time or Sludge Retention Time (SRT), Hydraulic Retention Time (HRT) and Organic Loading Rate (OLR) are key technoeconomic variables in designing and operating biodigesters which need to be thoroughly and thoughtfully derived and decided for an optimal performing bioreactor and methane output.

Biodigesters are also categorized based on capacities measured in cubic meters (m^3) or cubic feet (ft^3). Small biogas (SBG) are digester capacities in the range of 0 – 10m3 volume and typically for households, farms and commercial restaurant kitchens or cottage industry applications.

SBGs require small investment, less sophisticated and typically lack treatment and optimization units or system, gauge, stirrer, heater or any significantly expensive component. An SBG can be built using any container from water dispenser can to various sizes of kegs and emptied chemical drums or over plastic water tanks.

As single unit, medium biogas (MBG) have capacities between $10m^3$ and 100m3 while large biogas (LBG) have capacities above $100m^3$. Note that biodigester for commercial scales are usually constructed in modules for environmental, logistic, operational, technical and economic reasons as well as space management and aesthetic factors. ASPOG and Elfad collaboratively design and build biogas systems mostly in modules of between 30m3 and 100m3 for major projects in Nigeria with pipework and other services integrated accordingly.

Both SBG and LBG are commercial scale and typically include treatment units whether for gas sales or for estates, industries and captive production. Hence, a comprehensive Environmental Impact Assessment (EIA) has to be carried out alongside the fulfilment of other regulatory conditions that may apply.

Hence, the significance of biogas production from biodigesters aside from methane generated is the production of organic fertilizer effluent as a byproduct. The organic fertilizer includes the light liquid effluent decanted or drained from the digester as well the thick sludgy bottom liquid in the digester upon evacuation. New digesters often need inoculum which can be obtained as substrate from existing producing digesters.

Biogas is very much the same as LFG; the basic difference being that the former is derived from anaerobic digestion in a container while the latter is due to both aerobic and anaerobic digestion in landfill. With rising cost of energy, biogas is fast gaining ground especially in farms, rural dwellings and new commercial interests.

The quality of a biogas primarily depends on the feedstock or the source of raw material and could be animal or plan remains such as fresh cut grass, animal waste, animal remains, kitchen and food process wastes, sewage and so on. The quality and quality of animal waste varies with types and specie as well as nutritional quality and quantity similar to plant, wastewaters and kitchen waste varieties.

Biogas is a mixture of gases made up of 45% to 75% methane, being the energy gas and substance of interest; carbon dioxide, 20% to 50%; carbon monoxide, 0 to 3%; hydrogen sulphide; moisture, 1% to 5%; Nitrogen 0 – 10%; hydrogen 0 to 3% and trace gases 0 - 3%. Hence, the higher the fraction of methane in a biogas, the higher its quality and the more it compares with natural gas, which is made up of over 95% methane (ASPOG, 2021).

Aside from cooking or purpose, due to the high impurity of biogas especially with respect to hydrogen sulphide and carbon dioxide, it is not advisable to use crude(untreated) biogas to fuel power generators, engines or turbines or turbines due to the tendency of these acid gases present to foul the internal combustion system and rapidly corrode all metallic components on the fuel and exhaust paths except such power plant is designed specifically for direct biogas usage such as biogas generators. Hence a biogas needs to be upgraded by suitable sweetening stands in order to be safely used in fueling internal combustion engines just like conventional natural gases.

Biogas upgrade is the process of treating a crude biogas in order to reduce its impurities below maximum acceptable levels and increase the methane composition above 95% (IEA, 2018) in line with applicable regulatory standards so that such they are classified as biomethane or called renewable natural gas (RNG) which makes them fit for commingling, blending and flowing in city gate lines as normal pipeline natural gas(PNG) which may also be liquefied and called LBM(Liquefied Biomethane) much like Liquefied Natural Gas (LNG).

Cow dung and abattoir remains are the largest most common viable sources of biogas feedstock in Southwest Nigeria as is the case with most of Sub Saharan Africa as they are easily obtained free of charge or a minimal cost with logistics cost being the main challenge aside competing interests from farms in some cases coupled with government's indifference in most cases thus hampering sustainability of feedstock supply. However, with proper integrated sewage system designs and farm waste management planning, a consistent qualitative and quantitative commercial scale biogas production is easily sustainable with enabling regulatory environment. An estimated 227,500TPD of animal waste is generated in Nigeria which makes up over 60MTPA of the country's energy reserve (Ben – Iwo, 2016).

According the Federal Ministry of Agriculture and Rural Development, Nigeria consumes around 90,000cows per day with Lagos abattoirs alone accounting for 6,000 (Ogbe, 2017). Nigeria Consumes 360,000MT of beef annually with a reserve of about 20million cattle, 40million sheep, and 60million goats while some 30% of these slaughtered in the country's abattoirs daily are sourced from neighboring Niger, Cameroun, Mali, and Chad (Smith, 2019)

Sasu(2012) reported the population of major commercial domestic animals in Nigeria with poultry being 207,600,000 in 2012 and 1, 284,300,000 in 2050; Pigs 6,500,000 in 2012 and 21,100,000 in 2050; sheep 42,500,000 in 2012 and 78,200,000 in 2050; goats 80,800,000 in 2012 and 207,800,000 in 2050; cattle 20,700,000 in 2012 and 53,600,000 in 2050 while Nation Master(2019) reported a horse population of 41, 111 in Nigeria and Abdullahi(2020) in reference with the United Nations Food and Agricultural Organization(FAO) puts Nigeria's donkey population at between 900,000 and 1,500,000 (Abdullahi, 2020).

For biogas production, the carbon – to – nitrogen ratio (C/N) of an organic waste primarily determines the quantity and quality of methane generation (Tira, H. S. et al, 2019) as the higher the C/N ratio of an organic remain, the higher volume and quality of biogas as well as the slowness and stability of substrate's fermentation decomposition rate up to an optimal range of 20:1 and 35:1 beyond which the nitrogen level becomes inadequate for proper microbial growth and methanogenesis begins to reduce(Kalamdhad, 2022). Lower C/N ratio means more stinky and very volatile. Hence optimal value means less odour and high volume of biogas (Okolo et al, 2014).

Cattle dung have C/N ratio of typically 30:1 to 35:1 which is optimal with biogas gas generation of 50% to 75% and takes a longer time(more than 1 week) to start decomposing and liberating gas compared most droppings which actually starts producing from first day of anaerobic digestion and typically have C/N of around 6:1 and 25:1 (Homebiogas, 2022; Okolo et al, 2014) which is quite sub optimal given the relatively low volume of biogas produced. Sheep and goat dung typically have C/N ratio between 15:1 and 30:1.

Average C/N ratio for some other possible biogas feedstock includes: horse dung, 25:1; pig slurry, 6:1; chicken droppings: 31.5:1; water hyacinth, 20:1; jatropha leaf, 12.7:1; rye cover crop in a vegetative state, 26:1;rice husk, 220.1:1; fresh vetch,11:1; fresh alfalfa: 12:1; kitchen waste, 15:1; used poultry bedding,15:1; sheep and goat dung, 15:1; leguminous hay, 17:1; fresh grasses, 20:1; vegetable waste, 25:1; alfalfa hay, 25:1; fresh weeds, 30:1; garden waste, 30:1; used horse bedding, 45:1; peat moss, 60:1; leaves, 60:1; stalks of fresh maize, 60:1; oat straw, 70:1; wheat straw, 80:1; rye straw: 82:1(Primandari et al, 2018; Lindsey, 2018; Okolo et al, 2014).

According to Richards (2009), blending various plant and animal waste sources produces better balance of C/N ratios that makes for higher volumes of methane than would have been the actual result for a single source with much lower methane productivity. Hence blending of kitchen waste with sewage can e help enhance the biogas production from human waste for example.

Since horses and donkeys are not prevalent in Southern Nigeria and the fact that plant biomass has already been addressed under biodiesel and bioethanol based on 5% non – food crop marginal land area, the biogas potential evaluation in this study is based only the fecal remains of notably available livestock southwest Nigeria using national per capital values.

Average quantity of dung produced per cow per day is 29.5Kg which also produces 0.045m3 per kg of biogas (Saqlain, 2003; Zuru et al, 2001; Sage Answer, 2021). An average ship produces 2.7kg of dung per day; an average swine produces 9kg of slurry per day while an average chicken produces 0.15Kg of droppings per day and an average goat produces a manure of 0.4725Kg per day (Top Fertilizer, 2023).

The average goat produces 0.4m3 of biogas per kg of total solid (TS) matter (Zjup et al, 2021). Sheep dung produces 0.285m3 of biogas per kg (Bahieh et al, 2021). Swine slurry produces 0.22m3 of biogas per kg (Nagi and Wopera, 2012). Biogas volume per Kg of poultry is 0.07m3(Homebiogas, 2022).

In terms of biogas quality by sources, cow biogas is composed of 50% to 75% methane (Homebiogas, 2022); Sheep biogas is made up of 53.3% to 57% methane (Achinas et al, 2018); poultry biogas has methane content of 54% to 67%(Silva et al, 2021); swine biogas contains 28.79% to 66.88% methane(Moroshnichenko et al, 2020) while biogas content from goat manure is 61.8% to 88.15%(Mogami et al, 2006). The LHV of biomethane is about 36MJ/m3(IEA, 2018).

Livestock	2023 Southwest Population	Waste (MTPA/cow)	M3/Ton	Biogas M3/cow/yr.	$\%CH_4$ Range	AVG $\%CH_4$
Cattle	5382018.16	10.7675	45.00	484.5375	50 – 75	62.50
Sheep	10009505.35	0.7665	28.50	21.84525	53.3 – 57	55.15
Poultry	69453485.61	0.05475	70.00	3.8325	54 – 67	60.50
Swine	1804293.352	3.285	22.00	72.27	29.79 – 66.88	48.34
Goat	20966660.17	0.1723	40.00	6.892	61.8 – 88.15%	74.98

Table 3.4: Livestock population and biomethane production in Southwest

Livestock	**Population 2012**	**Population 2050**	**CAGR**	**Population 2023**	**Per Capita Livestock**	**Southwest Livestock**
Cattle	20700000	53600000	0.025353311	27263352.8	0.127587498	5382018.16
Sheep	42500000	78200000	0.016175898	50704525.27	0.237287892	10009505.35
Poultry	207600000	1284300000	0.049125265	351826178.4	1.646482078	69453485.61

Swine	6500000	21100000	0.031471141	9139895.991	0.042773039	1804293.352
Goat	80800000	207800000	0.025169404	106209499.2	0.497041004	20966660.17
TOTAL	**358100000**	**1645000000**		**545143451.6**	**2.551171511**	**107615962.6**

Table 3.5: Livestock population projection in Southwest Nigeria

Livestock	Biogas (m3/livestock/Year))	biogas(m3/year)	Mean CH4 Fraction	Biomethane (m3)	Energy (MWH)	Energy (MJ)
Cattle	484.5375	2607789624	0.625	1,629,868,515	17195112.83	58675266540
Sheep	21.84525	218660146.8	0.5515	120,591,071	1272235.799	4341278555
Poultry	3.8325	266180483.6	0.605	161,039,193	1698963.482	5797410933
Swine	72.27	130396280.5	0.4834	63,033,562	665004.0792	2269208232
Goat	6.892	144502221.9	0.7498	108,347,766	1143068.931	3900519576
TOTAL	**589.37725**	**3367528757**		**2,082,880,107**	**21974385.12**	**74983683836**

Table 3.6: Livestock Biomethane Power Potential in Southwest Nigeria

Pyrolysis is the anaerobic combustion to gasification of biomass under high pressure and temperatures 350◦C - 550◦C resulting in the production of solid, liquid, and gaseous fuels such as coal, bio-oil, and gas. Gasification is the anaerobic combustion of biomass or carbonaceous fuels under pressure and temperatures above 700◦C to generated synthesis gas also called syngas which is a mixture of methane (about 3%), hydrogen (about 20%), light hydrocar carbon, nitrogen, steam and carbon monoxide (about 8%) and carbon dioxide (about 10%)

Landfill Gas. CH4 generation and emission in landfills vary with season, cover soil type, waste and soil characteristics (Abushammala et al, 2018), which provides a guiding insight on engineering landfills for optimal generation and consequently improved power production from MSW. Landfills and MSW are serious waste management challenges common to all Nigerian cities and causing environmental health hazards (Ike et al, 2018)

4.0. Discussion of Results

Biomass is a great energy prospect for power generation in southwest Nigeria with a high score of 0.791 given a regional potential of 3.07X10^9MWH, for non – food Dedicate Energy Crops (DEC); 1.21 X $10^9$$m^3$ of biomethane or 6.64 X 10^6MWH, for landfill gas WtE scheme; 2.1 X 10^9m3 or 21.97 X 10^6MWH of biogas methane, for animal wastes and so on.

The TEREVI of biomass is 0.79184, which is well above the threshold of 0.7, making it commercially viable as further supported by the competitive cost of generation, which comes at $0.020200729/kWh for HOMER optimization, $0.01862/kWh for Matlab simulation, $0.024920091/kWh for LCOE, and $0.026459/kWh for TELCOE.

Biomass Energy is very commercially viable in practically all varieties, including biomethane, wood biomass, landfill gas, MSW, non–food DED, and so on. Figures. 4.1, 4.2, 4.3, and 4.4 show the various bioenergy resources potentials and sources as well as energy yields across Southwest Nigeria.

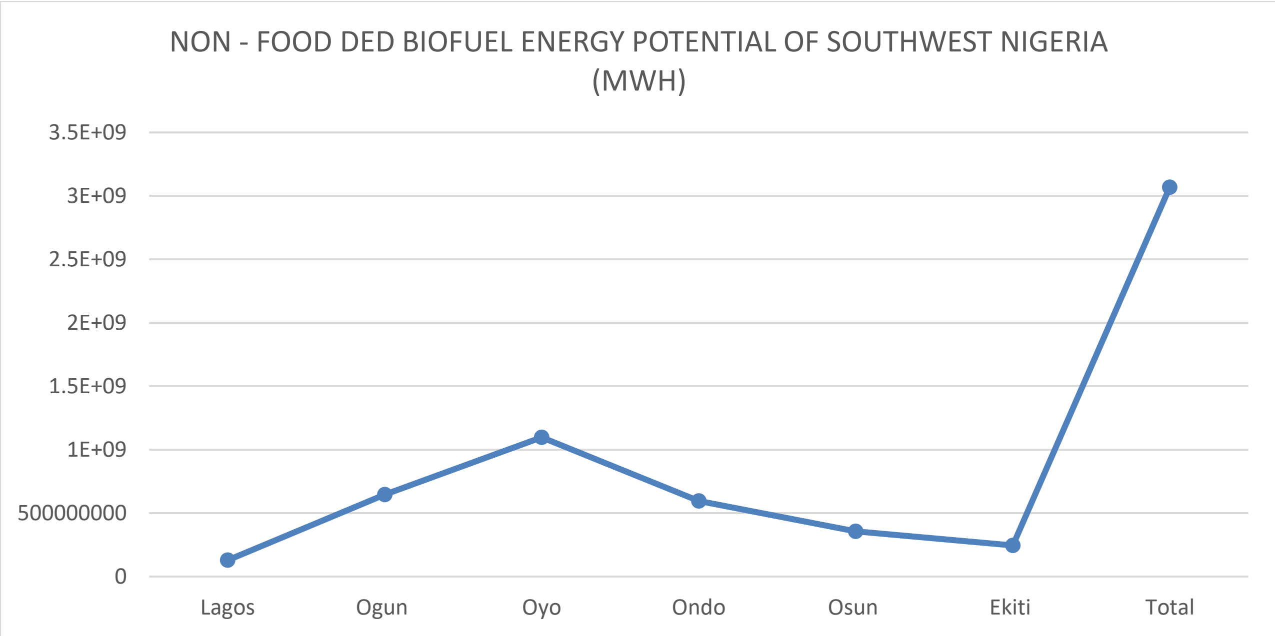

Figure 4.1: Non–Food Dedicated Energy Crop Energy Potential of Southwest Nigeria

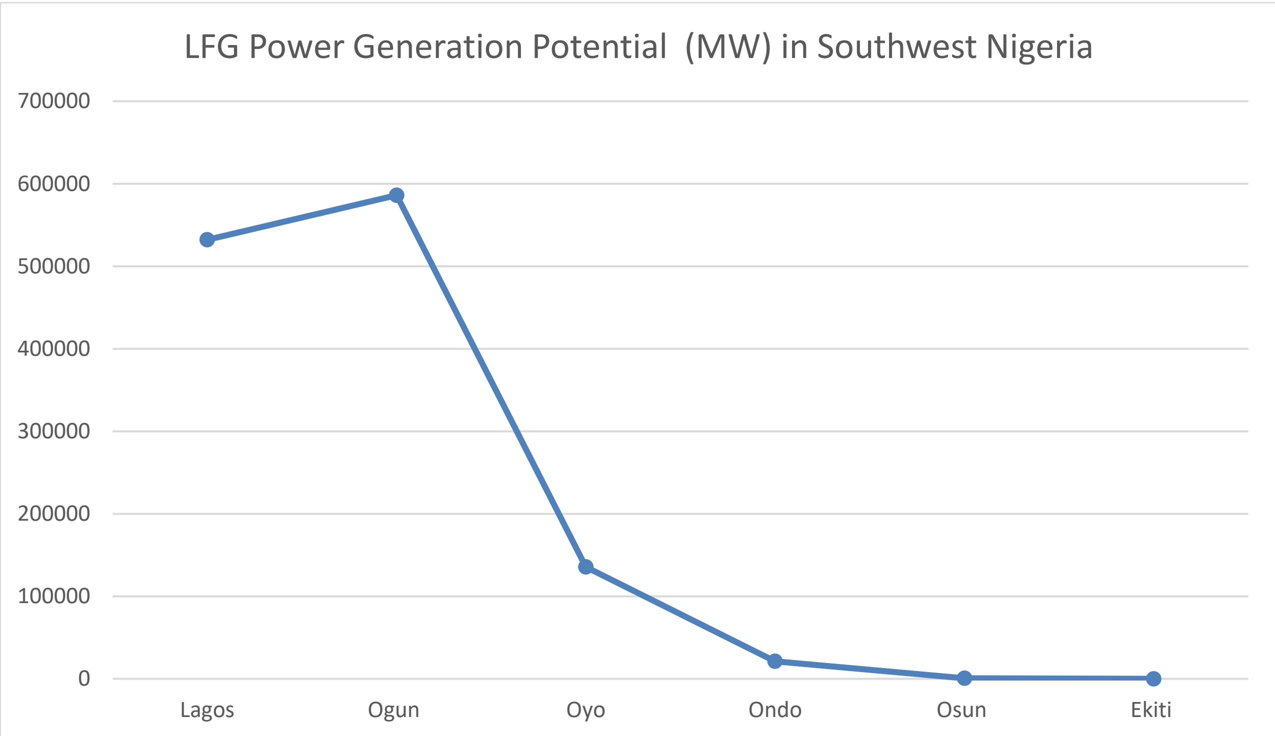

Fig. 4.2: Landfill Gas power potential of Southwest Nigeria

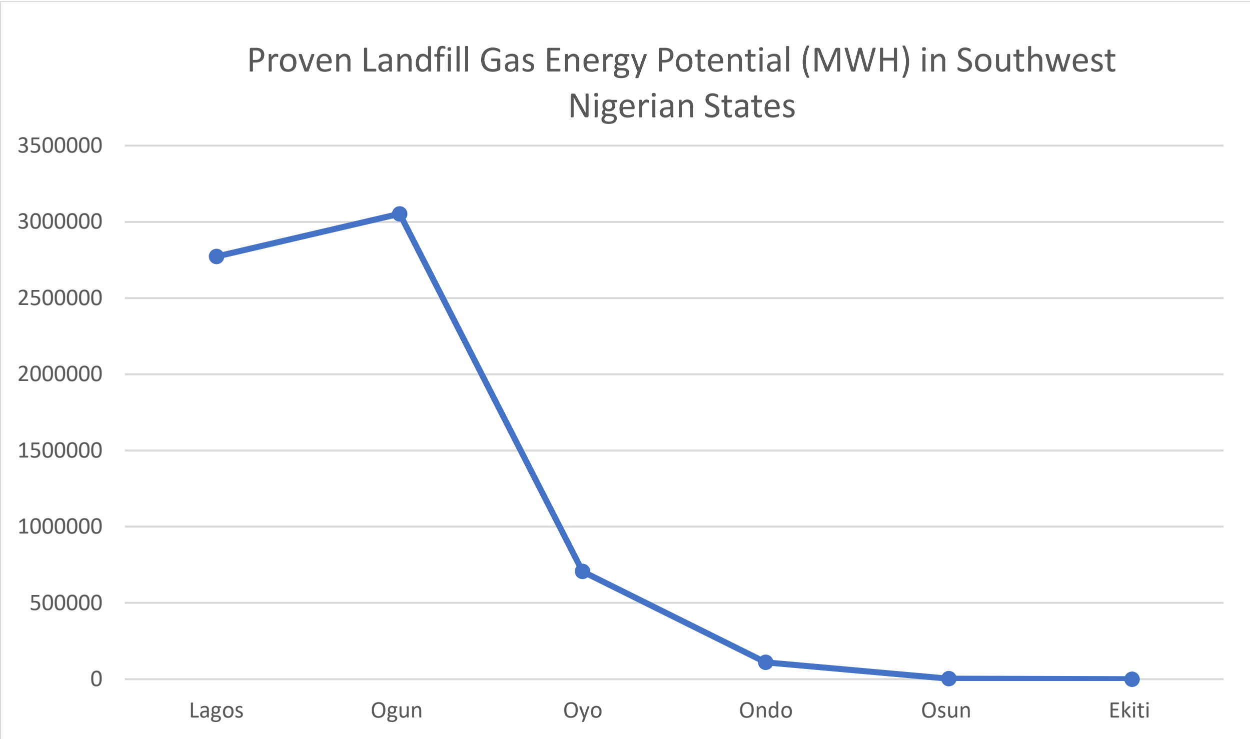

Fig. 4.3: proven LFG energy potential of Southwest Nigeria

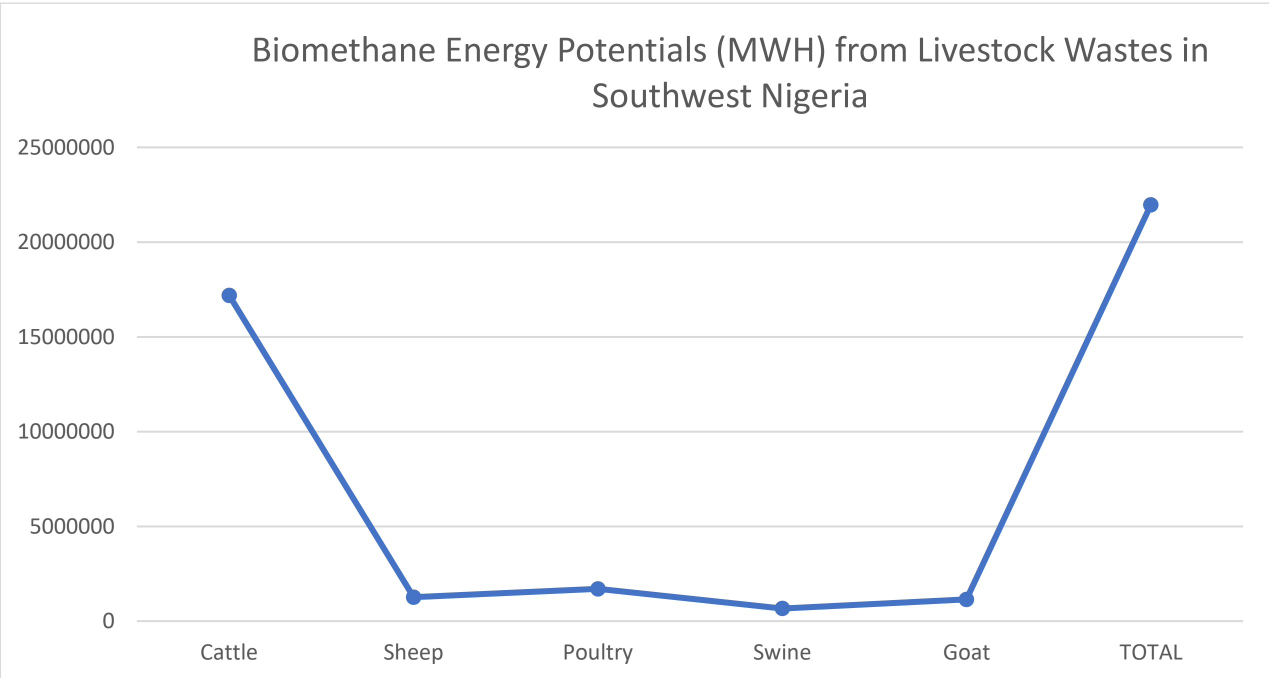

Fig. 4.4: Animal Biomethane potential of Southwestern Nigeria

Conclusion and Recommendation

Biopower driven mini-grid is the techno-economically the 6th most viable renewable energy solution to power shortage in Southwest Nigeria based on locally available and recoverable resources such as wood biomass, biogas from animal waste, non – food DEC, WtE power conversion system especially for rural and exclusive urban communities to minimize the cost and losses due to transmission lines and grid connectivity.

By the foregoing, there is an urgent imperative for the harnessing of bioenergy resources of all kinds for biopower generation as a short-term, medium-term, and long-term solution by ensuring proper documentation, preservation, repurposing, and recovery of applicable resources and materials where available

Biopower generation alone has the potential of meeting the electricity needs of rural and farm settlements, which constitute about 50% of the population and employment in southwest Nigeria, like in most of Sub-Saharan Africa.

Hence, a biopower energy data acquisition system needs to be established for optimized exploration and exploitation of the various bioenergy resources in the region or as part of the proposed Renewable Energy Data Acquisition of Nigeria (REDAN) in order to ensure effective planning.

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a. Conflict of Interest

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f. Authorship

I hereby declare that I, Christian Onuminya Okwori, is the only author of this research

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