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Harnessing Agro-Waste for Electricity Generation: A Pathway to Environmental Sustainability and Energy Poverty Reduction in The Niger Delta

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Abstract: The rural communities of the Niger Delta over the years have been faced with problem of energy poverty due to the fact that electricity has consistently been a scarce resources in the rural area. Agricultural waste in the Niger Delta has been growing exponentially as a result of several agricultural interventions in the region by government agencies, private and cooperate bodies.There is an increasing search for alternative cost-effective and environment friendly sustainable electricity source that will effectively reduce energy poverty in the Niger Delta region. This research is aimed at addressing the problem of environmental sustainability and energy poverty in the Niger Delta using agrowastes as bidigester feedstocks. The experimental method involved design of a small scale biodigester and using pig dungs, poultry droppings, cow dungs and cassava peels from LIFE-ND incubation centers as feedstocks.Four experiments were carried out using each agrowaste as feed stock.The collected agrowastes were each mixed with water in the ratio of 1:1 (40kg of agrowaste mixed with 40kg of water) to form a slurry and carefully poured in a biodigester and allowed to undergo anaerobic digestion for 25 days while daily biogas production was observed and recorded.The result from experiment shows that generally, all the feed-stocks used indicated a linear relationship between the volume build up against retention time. The retention time (days) that produces the maximum yield of biogas in volume are as follows: Cow dungs with 1,750 liters at 19 days, Pig dungs with 2,484.9 liters at 21 days, poultry droppings with 2,544.6 liters at 18days and cassava peels with 1,240.98 liters at 16 days, a total daily electricity contribution of 165.36Kwh , for every 1kg of agrowaste when effectively managed can generate about 0.09kwh of electricity, every 1kg of agrowaste when converted to biogas energy and used as substitute to conventional fuel sources can effectively reduce CO_2 emission into the atmosphere by (0.04-0.27)kg.

Keywords*: Agrowaste, Biodigester, Feedstocks, Retention Time, Energy, Emission Reduction, Sustainability.*

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I. INTRODUCTION

Agro-wastes are defined as residues from production and processing of agricultural products such as crops, poultry, diary products etc. They are non-product outputs of production and processing of agricultural products that may contain latent potentials that can benefit man but whose economic values on phase level are less than the actual cost of collection, transportation and processing for beneficial use.

Agricultural production plays an important role in economic development, food security, and rural livelihoods, particularly in regions with vast agricultural potential such as the Niger Delta of Nigeria. The area, known for its rich natural resources and favourable climatic conditions, has a diverse agricultural sector producing key crops like cassava, rice, cocoa, plantain, and oil palm. However, despite its potential, the efficiency and management of agricultural wastes production in the Niger Delta remain largely underexplored, with challenges related to indiscriminate dumping of agricultural wastes resulting in environmental pollution, health hazards, uncontrolled gaseous emission to the atmosphere, global warming and climate change. Understanding these adverse effects of agricultural waste play crucial role in formulating effective pathways in ensuring sustainable environment for efficient agricultural sustainability and economic growth without impinging on the livelihoods and distortion in the ecosystem[1].

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Energy plays an important role in global development. It is seen as a veritable foundation of economic growth, industrialization and social development[2].Energy is one of the most important factors for accelerating economic development. Biomass power which is electricity produced from biomass fuel is a renewable energy source is increasingly gaining attention and at the center stage for economic development[3]. Energy is a key factor for any form of socio-economic development and electrical energy has proven to be important among factors of production which include land, capital and labour[4][5] . In Nigeria 80% of organizations may rely on selfgenerated electricity[6]. Accessibility to electricity and the socioeconomic growth of a nation are connected[7][8] and is an essential factor in controlling the extent of rural-urban migration . Any nation with an electricity supply deficiency will experience declining economic growth, social problems and a low standard of living

Given the shortage of commercial energy resulting in energy poverty in Nigeria, the majority of rural communities and some fractions of urban dwellers utilized fuel wood and charcoal to meet nearly all their energy needs thereby provoking increased deforestation, green house gas emission, depletion of the forest reserves and its attendant climate change. Sambo[9]declared that fire wood and charcoal usage constitutes between 32%-40% of Nigeria's total primary energy consumption, with approximate annual consumption of 50 million metric tons of fuel wood alone. Also, self-generation of electricity is generally common and represents between 4,000 and 8,000 mega-watt (MW) [10].

The alarming rate of increase in the green house gases in the atmosphere it becomes necessary to develop sources of green energy while finding ways of reducing emission of harmful gases [11]. In contrast to fossil fuels, biogas energy offers source of clean energy and also helps in converting bio waste to usable form. In addition to this there is also a concern regarding satisfying the increasing energy demands.[12], [13].

One most striking feature of energy generation from biomass is that these are decentralised energy sources. Energy can be generated at a particular location depending on availability and then used directly at the same location in case of Biogas production also if the biomass is available which is causing nuisance, due to its organic nature then it can be converted to a form which will satisfy the energy need which will ultimately contribute to the energy mix[14-15]. Another benefit is that it will help to keep the surroundings clean and odour free which translate to effective agrowaste management for sustainable environment.

It is evident that different types of biodegradable agricultural waste can be used for generation of power. It involves forest waste, agricultural waste, cow-dung , poultry waste, cassava peels and and pig dungs. The time and conditions required for the conversion processes are different yet it ensures waste to energy and a cleaner surrounding for people to live. Modern technologies are enhancing the conversion process and making it simpler to work upon. Accumulation of such waste leads to harmful surroundings and so concerted effort must be made to utilize these agrowastes in most appropriate form.

A. Background

Nigeria has over time been faced with problem of low electricity supply at both national and rural areas levels; access to electricity remains at about 34% and 10% respectively[7][9] , this situation is worsened by the fact that rural communities account for over 60% of the country's total population[18][19]. In rural areas of the Niger Delta who are predominantly farmers, the low electricity supply problem has gradually eroded the local economy and stifled the development of cottage industries and small businesses [7] resulting in. rural-urban migration, unemployment, poor health (particularly to women using firewood and charcoal for cooking), social-cultural stagnation and depletion of forest and woodland in the country (over 90% of rural dwellers depend on fuel wood and charcoal)[9].

Various energy policies have targeted rural communities, with the aim of improving their energy access thereby curbing energy poverty: Consumer Assistance Fund and Rural Electrification [7] . Similarly, initiatives such as subsidising kerosene (cost Nigerian government over US$20 billion between 2010 and 2013) have had little or no impact [17] however, these policies appear not to have yielded the required results owing to the high cost of centralised electricity supply system using fossil fuel sources and grid network system, as they are typified with low capacity utilisation and are far from the grid, making it unappealing to private investor in providing electricity to these communities [9][17] . Thus,it becomes imperative to seek for a sustainable means of electricity provision that is not fully reliant on expensive grid extension systems (to reach rural villages) and fossil fuel (non-sustainable) sources is required. Hence, rural communities' electricity needs have to be met through sustainable, environmentally friendly and economical means; typically biogas energy from agrowastes have been used in providing sustainable electricity to rural areas in developing countries. This approach represents the most suitable alternative to fossil fuelbased systems, provides a foundation for future grid growth[4], has the advantage of reducing deforestation, helps in improving agrowaste management towards ensuring environmental sustainability and mitigating greenhouse gas (GHG) emission associated with fossil fuel sources, and creates more employment. Electricity generation using biogas costs far less than fossil fuel, application of biogas technology for electricity generation can help in waste management and provide a long term sustainable measure to energy self sufficiency, reducing energy poverty and economic development in the rural communities of Niger Delta [20].

Appropriate feedstock for electricity-generating biogas plants is available in adequate quantities in many countries. Small and medium-size biogas plants could provide a considerable contribution to national electricity generation in such countries. However, in comparison to industrialised countries, only very few small and medium sized biogas plants are used for electricity generation in Africa[20]. Electricity production from biogas can be a very efficient

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method for producing electricity from a renewable energy source. However, this technology have not really gained much attention in the Niger Delta in-spite of the huge amount of agrowaste generated and the near zero level of access to electricity in the rural communities.

This study will leverage on the agrowastes generated from LIFE-ND incubation centers and incubatee farms. The agrowastes will be used as feedstocks for biogas production and electricity generation.

B. Aim and Objectives

The aim of the research is to facilitate the effective management of agrowaste in the Niger Delta to ensure environmental sustainability and curbing energy poverty through conversion of agro waste to electricity.

➢ *To Achieve this Aim, the following Measurable Objectives have been Developed:*

- To explore the potentials of agrowastes generated in the Niger Delta as feedstocks for biodigester with emphasis on biogas production through anaerobic process.
- To provide an insight on the electricity generation potential of agrowaste generated in the Niger Delta towards curbing energy poverty.
- To provide information on emission reduction potentials of biogas as a substitute for conventional energy sources in the Niger Delta towards ensuring environmental sustainability.

II. MATERIALS AND METHOD

A. Setup of the Digester:

The digester utilized in this study is a 1 cubic meter (Plastic tank) aerobic digester designed for the production of biogas sourced locally. The digester is constructed using durable and impermeable materials to ensure optimal containment of gas and efficient digestion of organic matter. The design incorporates an inlet for the introduction of organic waste and two outlets, one for the collection of biogas and the second for the collection of liquid digestate (otherwise called liquid fertilizer).

Four sets of experiments were carried out for 25 days each using different agrowastes collected from the Livelihoood Improvement Family Enterprise -Niger Delta (LIFE-ND) agricultural value chain project incubation centers and incubatee farms. The agrowastes used as feedstocks for the four experimental setups were cow dungs, pig dungs, poultry droppings and cassava peels respectively.

B. Process of Biogas Production:

The process of biogas production within the digester follows the principles of anaerobic digestion . Agro wastes (cow dungs, pig dungs, poultry droppings and cassava peels) generated from LIFE-ND incubation centers and incubatee farms, is introduced separately into the digester through the inlet pipe. Inside the digester, microorganisms break down the organic matter in the absence of oxygen, resulting in the production of biogas as byproduct. The primary components of biogas are methane (CH_4) and carbon dioxide (CO_2), with methane being the main combustible component used for energy generation.

C. Collection of Agrowastes and Input into the Digester:

The collected agrowastes were each mixed with water in the ratio of 1:1 (40kg of agrowaste mixed with 40kg of water) to form a slurry, which facilitates the pumping and introduction of the waste into the digester. The input rate of the agrowaste for each of the experimental setup was carefully controlled to optimize biogas production while maintaining the stability of the digestion process.The inlet of the digester was covered tightly in each experiment and padded with a rubber seal to ensure adequate maintenance of anaerobic condition.

D. Measurement of Gas Production and Cooking Time:

Gas production from the digester is measured using gas volume displacement methods. A gas flow meter can also be used but is not available to me for use at the moment. The volume of biogas produced is recorded periodically, allowing for the assessment of production rates and efficiency. Additionally, the quality of biogas, including methane content and impurities, may be analyzed to ensure optimal performance.

To determine the cooking time provided by the biogas, practical tests were conducted using standard cooking appliances such as a single burner gas biogas stove. The biogas is supplied to the stove, and the duration of cooking time achievable with a specific volume of biogas recorded. This provides valuable insights into the energy output and practical utility of the biogas for cooking purposes, allowing for comparisons with other energy sources such as liquefied natural gas (LNG).

Fig 1 Experimental Setup

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III. RESULTS AND DISCUSSION

The Table 1 below shows the pressure build up and volume of gas generated during the biogas experiment using three types of agro waste feed stock from LIFE-ND incubation centers in Abayi Ohanze (poultry cluster), Umuahia (pig cluster) , cassava pilings from Obaha Nsulu, Isiala Ngwa North LGA and cow dungs from cow market in Umuahia Abia State.

Table 1 Volume of Biogas Produced in days

Feedstock	**Cow dungs**	**Pig dungs**	**Poultry droppings**	**Cassava Peels+ 1% Cow dungs**
Days	Volume (litre)	Volume (litre)	Volume (litre)	Volume (litre)
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.01
3	0.00	28.47	74.50	124.8
4	122.48	167.20	192.76	180
5	394.68	419.50	619.64	344.2
6	432.27	487.0	696.60	389.42
7	619.95	644.82	1159.11	421.3
8	645.18	1028.7	1230.32	481.20
9	709.62	1172.4	1529.43	524
10	681.17	1189.78	1312.15	586.72
11	871.56	1205.80	1359.63	651.90
12	871.22	1210.00	1539.54	748.20
13	1018.51	1218.60	1639.80	824
14	1020	1271	2199.66	902.4
15	1030	1312.50	2307.80	941.22
16	1036	1824	2395.39	1240.98
17	1255	1905	2450.77	890
18	1354.60	2225	2544.60	521.78
19	1750	2248.76	2140	210.33
20	1321.74	2398.45	1220	230.12
21	854	2484.90	657	120.76
22	409	1532.85	301.34	80
23	135	750	220	42.80
24	110	410	109	17.01
25	70.32	245	84	11.5

➢ *Discussion and Interpretation of results in Table 1*

Table 1 shows the results from experiments carried out using a model biodigester with four types of agricultural waste as feedstocks . Column 1 indicates the retention time in days, while columns 2,3, and 4 are the Volume buildup in biogas production using cow dungs, pig dungs, poultry droppings and cassava peels as feedstocks. respectively.

- The results show s that the biogas volume build up is directly proportional with time.
- The Substrate decomposition begins as from day 2 and gradually the volume increased with respect to time.
- During the process of fermentation, the volume of the feed is gradually increased which indicates decomposition of the substrate that was put inside the digester.

A graphs analysis of volume buildup against retention time is shown in Figures 1 Although biogas production began at day 2 from the graph, there was gradual increase as the fermentation process continues with respects to change in days. The production rate can be determined by the trend line equation of the graph.

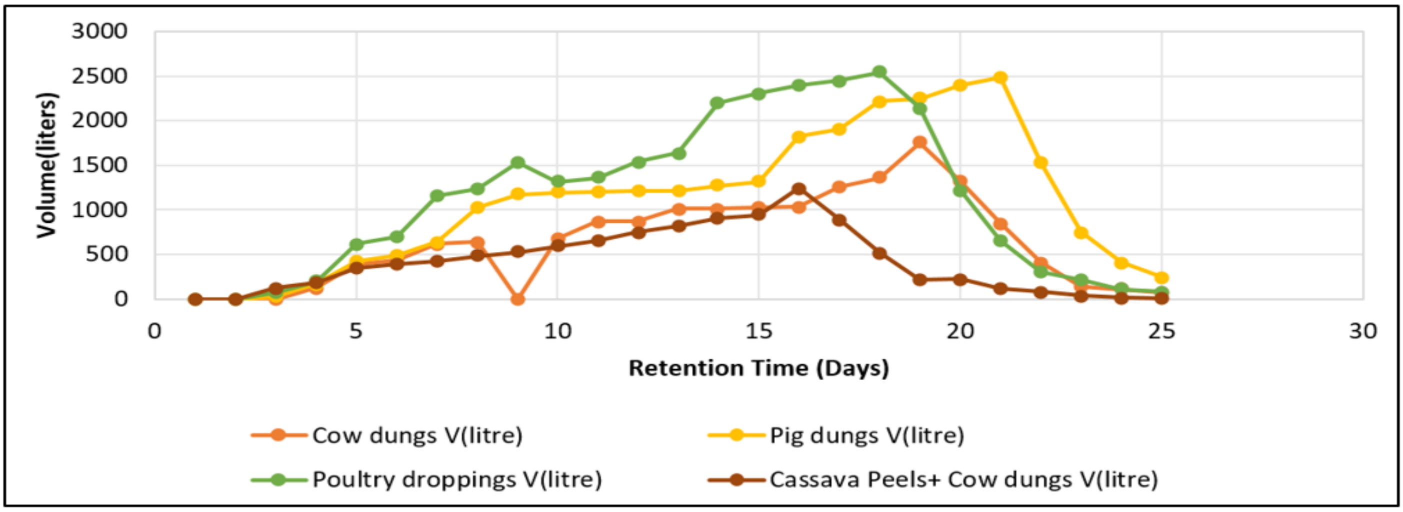

Fig 1 A graph of Volume of gas build up against days

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➢ *Discussion and interpretation of graph in Figure 1*

A graphs analysis of volume buildup against retention time is shown in Figures 1 Although biogas production began at day 2 from the graph, there was gradual increase as the fermentation process continues with respects to change in days. The production rate can be determined by the trend line equation of the graph.

- The Figure 1 shows the trends of volume buildup with days for the four feedstocks used in the experiment.
- Generally, all the feedstocks used indicated a linear relationship between the volume build up against retention time.
- The retention time (days) that produces the maximum yield of biogas in volume are as follows: Cow dungs with 1750 liters at 19 days, Pig dungs with 2484.9 liters at 21 days, poultry droppings with 2544.6 liters at 18days and cassava peels with 1240.98 liters at 16 days.
- The results Shows that at a feedstock volume of 40kg, the retention time that gives optimal biogas production ranges from 16 to 21 days.

➢ *Biogas Energy Production potentials*

The biogas energy production potentials and retention time for the four feed stock from the experiment is presented in Table 2.

Table 2 Biogas energy production

Feed-stock	**Retention time(Days)**	**Volume(m^3/Kg)**	**Agrowaste(kg/day)**	**Volume(m^3/day)**	**Energy (MJ/day)**	**Energy (Kwh)**	**Electrical Energy(Kwh)**
Cow dungs	19	0.044	360	15.84	348.48	97.57	34.15
Pig dungs	21	0.062	10	0.62	13.64	3.82	1.34
Poultry droppings	18	0.064	360	23.04	506.88	141.93	49.68
Cassava peels	16	0.031	1200	37.2	818.4	229.15	80.20
TOTAL			1,930	76.7	1687.40	472.47	165.36

➢ *Discussion and Interpretation of Result in Table 2*

Table 2 above shows the Biogas energy production potentials and associated energy contribution to the Niger Delta LIFE-ND to curb energy poverty and ensure energy access in line with the Sustainable Development Goals for Energy (SDG7) which is to ensure access to affordable, reliable, sustainable and modern energy for all.

- Column 1 shows the feed-stock used in the experiment,
- column 2 shows the maximum retention time for each of the feed-stock that produced the highest biogas by volume,
- column 3 shows the volume of biogas produced per kg of feed-stock, column 4 is the average daily agro waste produced in the LIFE-ND incubation centers/clusters,
- Column 5 (Column 3 multiplied by column 4) is the Expected volume of biogas produced per day for each of the feed stock ,
- Column 6 is the value of the Expected Energy generated (Column 4 multiplied by 22 MJ), (vii) Column 7 is the Energy in KWh (column 6 multiplied by 0.28),
- Column 8 is the Electrical Energy equivalent (Column 7 multiplied by 35%)

The Table 2 shows that cow dungs feed stock with a retention time of 19 days has the potential of producing 0.044 m^3 of biogas per kg of waste which is equivalent to: 15.84m^3 of biogas per day; 348.48 MJ of energy per day; 97.57 KWh of energy per day;and yearly energy contribution to the National Energy of 127543.68 MJ.

The pig dungs used as feed stock with retention time of 21 days has the potential of producing 0.062 m^3 of biogas per kg of waste which is equivalent to: 0.62m^3 of biogas per day; 13.64 MJ of energy per day; 3.82 KWh of energy per day; and yearly energy contribution to the National Energy of 4992.24MJ.

The poultry droppings used as feed stock with retention time of 18 days has the potential of producing 0.064 m^3 of biogas per kg of waste which is equivalent to: 23.04m^3 of biogas per day; 506.88 MJ of energy per day; 141.93 KWh of energy per day; and yearly energy contribution to the National Energy of 185518.08 MJ.

The cassava peels used as feed stock with retention time of 16 days has the potential of producing 0.031 m^3 of biogas per kg of waste which is equivalent to: 37.20m^3 of biogas per day; 818.4 MJ of energy per day; 229.15 KWh of energy per day; and yearly energy contribution to the National Energy of 299534.40 MJ.

- The total daily electricity contribution is 165.36Kwh
- The experiment shows that for every 1kg of agrowaste when effectively managed can generate about 0.09kwh of electricity

➢ *Biogas Energy Content Comparison*

The Energy content comparison for biogas energy with conventional energy sources(firewood, charcoal kerosene and liquefied petroleum gas (LPG)[21] is presented in Table 3

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Table 3 Energy content comparison

Amount and Type of Fuel	Volume of Biogas with same energy content (m^3)	Volume of Biogas from feed stocks with same energy content (m^3)			
		Cow dungs	Pig dungs	Poultry droppings	Cassava peelings
1kg firewood	0.25	15.84 (63.36Kg)	0.62 (2.48kg)	23.04 (92.16kg)	37.2 (148.8kg)
1kg charcoal	0.65	15.84 (24.37kg)	0.62 (0.95kg)	23.04 (35.45kg)	37.2 (57.23kg)
1 liter kerozene	1.60	15.84 (9.9liter)	0.62 (0.39 liter)	23.04 (14.4 liters)	37.2 (23.25litres)
1kg LPG	2.10	15.84 (7.54kg)	0.62 (0.3kg)	23.04 (10.97kg)	37.2 (17.71kg)

➢ *Discussion and Interpretation of Result in Table 3*

- The Table 3 shows the energy content comparisons.
- Column 1 indicates the amount and type of fuel (conventional fuel) in kg and liters as appropriate.
- The column 2 shows the volume of biogas with the same energy content.
- Columns 3, 4,5 and65 shows the volume of biogas from experimental feedstocks with the same energy content.
- The Table above shows that 1kg of firewood has the same energy value as 0.25 m^3 of biogas this translates to 63.36 kg, 2.48kg, 92.16kg and 148.8kg firewood energy. It implies that 63.36 kg, 2.48kg, 92.16kg and 148.8kg of deforested trees would be prevented daily by using the average daily agricultural waste production for cow dungs, pig dungs, poultry droppings and cassava peels biogas as substitute for energy production.
- (vi)The result from the Table shows that 1kg of agrowaste when converted to biogas energy and used as substitute to conventional fuel sources can effectively produce clean energy equivalent between the range of (0.02-0.17)kg
- Table 3 shows that Biogas produced from pig dung or other organic waste materials can provide a reliable and renewable source of energy for cooking purposes.
- The energy output of biogas is comparable to that of natural gas, with methane being the primary combustible component.

➢ *Emission Reduction Potentials of Biogas*

The emission reduction potential of biogas as substitute for conventional energy sources [21] is presented in Table 4

Table 4 Emission Reduction Potentials of Biogas as Substitute for Energy and fuel

Amount and Type of Fuel	Emission from fuel use Kg(CO_2)	Emission Reduction			
1kg firewood	1.7	(63.36Kg) 107.71	(2.48kg) 4.22	(92.16kg) 156.67	(148.8kg) 252.96
1kg charcoal	3.45	(24.37kg) 84.08	(0.95kg) 3.28	(35.45kg) 122.30	(57.23kg) 197.44
1 liter kerozene	2.5	(9.9liter) 24.75	(0.39liter) 0.98	14.4(liters) 36	(23.25litres) 58.08
1kg LPG	1.9	(7.54kg) 17.33	(0.3kg) 0.57	(10.97kg) 20.84	(17.71kg) 33.65
AVERAGE		58.47	2.26	83.95	135.53

➢ *Discussion and Interpretation of Result in Table 4*

The Table 4 presents the Emission reduction potentials of biogas as substitute for energy and fuel. Emissions from biogas use are zero, so emissions reductions are calculated by multiplying the reduction in fuel use (after switching to biogas) by the amount of carbon dioxide that would have been emitted from burning those fuels.

- Column 2 is the emission on fuel use per kg of conventional energy sources (firewood, charcoal, kerozene and LPG).
- Columns 3,4, 5, and 6 are emission reduction potential per day when used as substitute for fuel.
- The Table 3.3 shows that when biogas from agrowastes are used as a substitute energy sources for heating and lighting in the LIFE-ND incubation centers and clusters an average total of 58.47, 2.26, 83.95 and 135.53 kg amount of CO_2 emission to the atmosphere will be reduced when cow dungs, pig dungs, poultry droppings and cassava peels respectively are used as biodigester feedstocks.
- (iv)The result from the Table shows that 1kg of agrowaste when converted to biogas energy and used as substitute to conventional fuel sources can effectively reduce CO_2 emission into the atmosphere by (0.04-0.27) kg.
- The Table 4 shows that Biogas production significantly reduces greenhouse gas emissions by capturing methane, a potent greenhouse gas, and converting it into energy. Methane emissions from organic waste decomposition are a major contributor to global warming.By capturing methane through anaerobic digestion, biogas production helps mitigate climate change and reduces the environmental impact of organic waste disposal.

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IV. CONCLUSION

This study highlights the importance of agrowastes as feed-stocks in biogas production for electricity generation towards achieving environmental sustainability and energy poverty reduction in the Niger Delta. The experimental method involved design of a small scale biodigester and using pig dungs, poultry droppings, cow dungs and cassava peels from LIFE-ND incubation centers as feedstocks.Four experiments were carried out using each agrowaste as feed stock.The collected agrowastes were each mixed with water in the ratio of 1:1 (40kg of agrowaste mixed with 40kg of water) to form a slurry and carefully poured in a biodigester and allowed to undergo anaerobic digestion for 25 days while daily biogas production was observed and recorded.The result from experiment shows that generally, all the feed-stocks used indicated a linear relationship between the volume build up against retention time. The retention time (days) that produces the maximum yield of biogas in volume are as follows: Cow dungs with 1,750 liters at 19 days, Pig dungs with 2,484.9 liters at 21 days, poultry droppings with 2,544.6 liters at 18days and cassava peels with 1,240.98 liters at 16 days, a total daily electricity contribution of 165.36Kwh , for every 1kg of agrowaste when effectively managed can generate about 0.09kwh of electricity, every 1kg of agrowaste when converted to biogas energy and used as substitute to conventional fuel sources can effectively reduce CO_2 emission into the atmosphere by (0.04-0.27)kg.

According to the results, electricity generation from biogas considered as a reliable option of improving energy reach in the agrarian rural communities of Niger Delta thereby curbing energy poverty.The result has also shown that the use of agrowaste as feed stock biogas production also reduces CO_2 emission into the atmosphere thereby reducing the environmental issues of global warming.

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