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A survey of deployment of renewable energy systems with emphasis on biomass energy for local slaughterhouses

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ABSTRACT

Energy is needed for agricultural activities, water supply, lighting, healthcare, education, business and communication among others. Unfortunately, this is not constantly available from the national grid. The inability to access a reliable energy supply has forced a large number of people, businesses and corporate organizations to supplement their energy needs using generators that depends on diesel or petrol as a fossil fuel. However, the cost of purchasing diesel and petrol has been exorbitantly higher in recent times, in addition to the danger associated with emission of gases from its combustion. Against this background, this research focuses on reviewing the deployment of renewable energy resources (RES) with an emphasis on biomass energy for local slaughterhouses. Relevant articles were downloaded from reputable outlets and carefully sorted based on the objective of this paper. The reviewed articles presented viable techniques for energy production from slaughterhouse waste, challenges, prospects and future road-map for energy generation from slaughterhouse waste. The outcome of this research revealed that a good number of pilot projects are known to fail within a short period after implementation and the sustainability of energy generation from direct waste such as animal dung and extract waste from cows after slaughtering. It is also noted that biomass which is vastly available in sub-Sahara Africa has been scantly deployed in the hybrid energy system. The review is a guide and eye opener to the direct use of biomass waste resources for direct applications for combating energy poverty in many sub-Saharan African countries.

Keywords: Biomass energy, slaughterhouse, renewable energy resources, hybrid energy and energy poverty

1. Introduction

Accessibility to electricity is a vital socio-economic factor capable of facilitating the rapid development of developing countries across the globe (Zhang *et al*, 2019). It is also a known fact around the globe that communication, health services, business, and education among others depend on a reliable supply of electricity. However, a reliable supply of electricity in Sub-Sahara Africa is a hurricane task that appears insurmountable as a good number of countries that are domiciled in this part of the globe have the lowest energy access compared to the rest of the world (Blimpo *et al*, 2019). It has equally been reported that electricity reaches only about half of the people which implies a rough estimate of 770 million people lacking access to electricity in Asia and Africa (Blimpo *et al*, 2019). This inability to provide sustainable and reliable electricity has limited the existence of key indexes that can be used to measure the growth and development of man. In the past, fossil fuel has been the traditional way of providing energy, and diesel fuel being a foremost member of fossil fuel material was grossly believed to have the ability to supply a predictable energy which does not depend on climate but its attendant challenges on the environment, high operation /maintenance cost and climate change have become a clarion call for an alternative source of energy. Hence, the transition to green energy becomes a necessity, for instance, the United Nations spelt out four critical areas where priorities should be given which are; energy security, climate change, poverty and drinking water (Lin *et al*, 2016). Energy security implies uninterrupted access to the populace's affordable, reliable, and sustainable energy supply. In fulfilling this mandate, the need to encourage alternative sources of energy and /or the combination of conventional energy sources with renewable sources of energy cannot be compromised.

Renewable sources of energy which includes; solar, geothermal, hydro, wind, tidal and biomass must be enhanced to complement the conventional energy sources which has become

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Researchers have also discovered that renewable sources of energy is not efficient in providing a sustainable and reliable energy due to its climate dependency. Energy resource such as solar depends on the intensity of sunshine during the day and at nights or the days when the sun does not shine, the efficiency of the energy drops and thus affecting the production of electricity. Also, the efficiency of the wind energy depends on the velocity of the wind, the hydro energy depends on the volume of water and flow rate, biomass resource depends on the sources of the resource which could be animal, agricultural etc. All these renewable sources of energy suffer natural variations which invariably affect their performances. Thus, the integration of both renewable and non-renewable energy sources to form a hybrid energy system is a giant stride in providing a stable, reliable, affordable and environmentally friendly energy for human consumption (Lazarov *et a*l, 2005). This hybrid energy can be used to service several area of applications such as lightning of community health Centre, rural electrification, water pumping for irrigation and slaughter houses, among others. Unlike solar and wind which are not direct by-product of any of man's activities, the gas produced from biomass is a direct product of man's activities such animal waste, cow dung, slaughterhouses / abattoirs waste. For instance the ability to extract biogas from slaughterhouses/abattoirs waste is a better way of managing waste disposal into the atmosphere and in the recent time, biogas energy production from these sources is becoming popular and growing towards maturity. It is imperative to know that researchers that have extensively explored the viability of green energy production from solar and wind, while biomass resources is scantly researched despite being plentiful in supply. It is an area of renewable energy that is still very green to be explored for energy production. Slaughter houses/abattoir wastes can provide the green energy which can sufficiently be used to provide energy for business sectors and the rest excess energy can be sold to nearby households to supplement their energy demand/requirement from the national grid. On these premises, the core concern of this current paper is the review of deployment of renewable energy systems with emphasis on biomass energy for local slaughterhouses.

2. Sources of biomass energy

Biomass could be generated from animal waste, municipal waste, agricultural waste, crop residues and toilet waste. These sources have greater potentials to produce sustainable energy when enhanced and extracted (Khan *et al,* 2015). These biomass resources are vastly available in rural areas as wood-fuel, agricultural residue or crops, animal waste (cattle dung, chicken litters). These renewable resource has not been thoroughly explored for production of electricity. Biomass resource is used to generate bio-fuel (biogas) which is used as a fuel to drive a bio-generator to complement other sources of energy in the design to ensure a reliable, affordable and sustainable production of electricity to consistently meet the energy demand of the location

2.1 Techniques of extraction of green energy from specific biomass resources

Several of man's activities can generate biomass resources, for instance, animal dung, municipal waste and cow dung among others are the principal sources of biomass energy. Biomass as sources of energy is extracted through two major methods: thermo-chemical methods and biochemical methods (Garba, 2020). Biomass has proved to be a sustainable potential source of fuels which can be used for generating electricity and as a fuel for other machinery when the stored energy in it is extracted. For instance, wood as biomass resources has been used as source of energy for cooking and for heating applications especially in the cold regions of the world. Central to the process of extraction of biogas from biomass is the temperature and the amount of oxygen. These two key factors, to a large extent determine the energy yield during conversion process.

2.2 Thermo-chemical methods

It is pertinent to know the subset of thermo-chemical methods which are drying, torrefaction, carbonization, pyrolysis, gasification and combustion (Hitlz *et al,* 2015; Bergman, 2005) and the chemical equations for these approaches are as detailed in Table 1. The dynamics of extracting bio-energy from biomass is as detailed as follows;

i) Hydro-thermal carbonization (HTC): carbonization is a process of heating fuel in the absence of air to leave only porous carbon**.** The condition of this process is that biomass should be heated between 180–250°C.

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Table1: Chemical equation description of thermo-chemical process of extracting biomass energy (Garba, 2020; Hitlz *et al,* 2015)

Method	**Process Tempera-ture**	**Chemical Reaction**	**Remarks**
Hydrother-mal Carbon-ization (HTC)	180 -250^{0}C	$CH_{1.4}O_{0.6}+H_2O \rightarrow$ hydrocarbon + gaseous and liquid residues	solid fuels are some of the products
Torrefaction	280-550 ^{0}C	$CH_{1.4}O_{0.6} \rightarrow C$ + tar + $0.6H_2O + 0.1H_2$ and other gas products	Coke briquettes
Slow pyrol-ysis (carbonizati on)	280-550 ^{0}C	$CH_{1.4}O_{0.6} \rightarrow C$ + tar + $0.6H_2O + 0.1H_2$ and other gas products	
Fast pyroly-sis	500-800^{0}C	CH1.4O0.6 → about 200 different volatile compounds (oil, tar) + C + CO + H_2O + H_2 + and other flammable gases	About 200 different volatile materials and other flammable gases are the products
Gasification	800-1000^{0}C	$CH_{1.4}O_{0.6}+0.2O_2 \rightarrow CO+0.7H_2$ (theoretically), $CH_{1.4}O_{0.6}+0.4O_2 \rightarrow 0.7CO + 0.3CO_2 + 0.6H_2 + 01H_2O$ (technically)	
Supercritical steam gasifi-cation		$CH_{1.4}O_{0.6} + 1.4\ H_2O \rightarrow CO_2 + 2.1\ H_2$	
High-temperature steam gasifi-cation	>1000^{0}C	$C_mH_n + 2m\ H_2O \rightarrow m\ CO_2 + (2m + n/2)\ H_2$	
Combustion		$CH_{1.4}O_{0.6} + 1.05\ O_2 + (3.95\ N_2) \rightarrow CO_2 + 0.7\ H_2O + (3.95\ N_2)$	Less encourage due to prevalent effects on the atmosphere and environment

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ii) Torrefaction is also a thermo-chemical process which is aimed to decrease the water and volatiles contents from the biomass and the condition of conversion is expressed as;

Biomass (200–300 °C) → 30% (gases + volatiles) + 70% torrefied biomass (biochar) (1)

iii) Slow pyrolysis (carbonization) when organic materials is subjected to combustion without presence of oxygen, its condition of conversion is as described with equation (2);

Biomass+O_2 (a small amount at the beginning) (280–550°C) →biochar and other gas products (2)

iv) Fast pyrolysis: This is the rapid heating of biomass material in the absence of oxygen. Its condition of conversion is as showing in equation (3);

Biomass (500–800 °C) → biochar + oil + flammable gas (3)

v) Gasification: this is another technique of conversion of biomass to biogas and as described using equation (4) thus;

Biomass + O_2 (limited amount) (800–1000 °C) → flammable gas (4)

vi) Super-critical steam gasification: this technique is adopted for the conversion of wet biomass that has high water content to syngas. The technique is as described using equation (5) thus;

Biomass + H_2O → H_2 + CO_2 (5)

vii). High temperature steam gasification; its yield process is as shown with equation (6) thus;

Biomass + H_2O (>1000 °C) → CO_2 + H_2 (6)

viii). Combustion: This process is not very encouraged because it releases a lot of emissions which deplete the environment and as described with equation (7);

Biomass + O_2 (stoichiometric amount) → thermal energy + flue gas (7)

2.3 Biochemical process; approach for biomass conversion of abattoir/ slaughterhouse waste

Slaughterhouses/abattoir produces a sustainable waste that can be used to generate biogas through biochemical process or thermo-chemical process as described above (Valerio *et al*, 2018). Bio-chemical conversion of biomass on the other hand entails utilization of the bacteria or microorganisms to disintegrate biomass by anaerobic process, fermentation or compositing. The two major processes involved in the biochemical conversion of biomass are anaerobic digestion and fermentation. The anaerobic digestion is the process of breaking down the biomass or organic waste by enzymes of bacteria in the absence of oxygen to produce biogas (methane and CO_2) and bio-fertilizer (Achinas *et al,*2020) while fermentation process is the conversion of organic waste to alcohol or acid (ethanol or Lactic acid etc) in the absence of oxygen. Temperature has a significant role to play in the conversion process of biomass. In the Bio-chemical, bacteria operating temperatures are categorized into mesophilic (20-40^{0}C) condition, pyschrophilic (< 20^{0}C) and thermophilic (>55^{0}C) (Russell & Fukunaga, 1990).

However, there are few exploration carried out on bio-waste generated from the slaughterhouses despite enormous quantity of cow dung and paunch generated daily from slaughtered cattle. Biogas produced by either process has capability to fuel bio-generators to produce electricity for the slaughterhouse, rural or remote area. Research has also shown that the biogas is eco-friendly and the resources are available locally as animal wastes or crop residues which could easily replace fossil fuel utilization, and mitigating the associated challenges of climate change and the attendant issues of CO_2 on the environment (Russell & Fukunaga, 1990). Despite the volume of biomass from the slaughterhouses, the potential energy reserved in the resources has not been adequately harnessed to create energy value for utilization whether as bio-fuel to generate electricity or heating.

2.4 Reliability and sustainability need: a call for a hybrid energy system

The provision of energy requirement for most slaughterhouses has been by single energy source or combination of two or more energy sources in a faction described as hybrid energy system. Hybrid energy system is the combination of conventional energy sources and renewable energy sources to produce a reliable and sustainable energy. In power system engineering, one renewable and one conventional energy sources can be combined and used to produce electricity as a standalone

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(Distributed generation) or grid connected system (Homer Pro,3.10.3 edition). The output from the hybrid energy system could be AC, DC or both AC and DC which are connected to bus bar where the loads access the power. In designing a sustainable hybrid system, thorough analyses have to be carried out in four different stages such as the drafting of design, detail design, implementation and post implementation analyses. These four stages are critical to the sustainability of the hybrid energy projects (Anna *et a*l, 2022).

Each renewable energy source is subjected to stochastic characteristics of nature, and to overcome this challenge, hybrid system is usually proposed, and a typical topology of a hybridized energy systems comprising of solar PV, wind turbine, Bio-generator and mini-hydro generator is as shown in Fig.1. The sources of energy are employed to compliment the energy output of each other so as to achieve sustainability and reliability regarding the energy generation. Also, variability of weather is another key factor contributing to low efficiency of renewable sources (Urmee & Md, 2016) and according to scholarly works, the energy conversion outputs of solar PV varied between 15 - 22 % (Olabode *et al,*2021), wind turbines only convert energy in an estimated percentage of 30-35 % (Vidyanandan,2017; Li *et al*,2022) while tidal energy conversion is about 80 % (United state Environmetal Agency Fact sheet, August 2013;New world enclopedia,2020). Considering these shortfalls in energy conversion, it is pertinent for engineers to see how these challenges could be overcome by complementing the renewable energy sources, to this end we critically examine work that has been done to appreciate the beauty of energy generated via biomass resources.

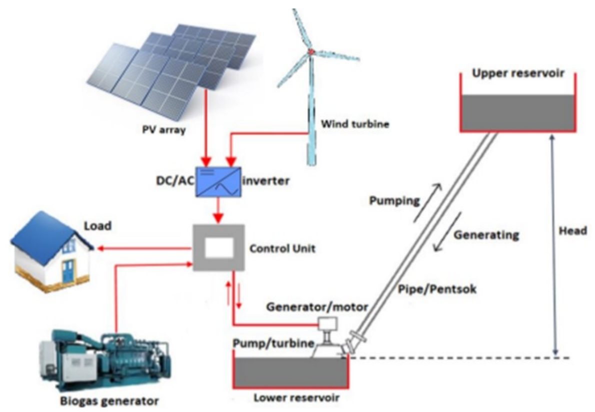

Fig.1. Topology of hybrid energy systems (Yimen *et al*, 2018)

3. Bio-energy for slaughterhouses

The study described in (Gorizalez *et al,* 2014) focused on the Iberian pig slaughterhouses in Extremadura (Spain), which are important to the region's economy and produce a lot of moist, highly polluting organic waste that must be handled in an environmentally responsible manner. On the other hand, the energy prices (electricity and fossil fuels) have a propensity to rise steadily, which is gradually lowering the financial returns of these businesses. This study offers a comprehensive answer to the energy and environmental issues faced by businesses that produce wet waste biomass. This approach combines solar photovoltaic electricity with biogas produced by anaerobic digestion of these wastes. The results indicate that installing these systems would be the most cost-effective, viable and sustainable solution in the particular instance of this Iberian pig slaughterhouse. Also in Ghana, a research work carried out as presented in (Francis *et al,* 2020) employing a multi-criteria analysis (MCA), demonstrates the potential usage of a hybrid power system as a substitute sustainable energy source in Ghana using a biogas and solar photovoltaic (PV) system. The assessments take into account the producing capacity for three commercial sites in relation to feeding into the national grid (FiT), self-consumption (Pro-sumers), and irrigation of agricultural land. The outcome demonstrates that it is possible to combine solar PV and biogas. It also demonstrates that with the use of smart energy control systems for community-based and important applications and manual changeover for minor, non-critical applications.

Rimong and Jumaat (2021) investigated biogas as one of the renewable sources of energy that can help to solve the problems of CO_2 emission, exorbitant cost of running diesel generator and ecological depletion as a result of climate change. The efficiency and performance of this resource were carried out using MATLAB/Simulink while municipal solid waste was the main source of input which was taken from Malaysia and Parit Raja. The waste material undergoes various stages such as hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The CH_4 and CO_2, H_2S, and

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water molecules are the final products. Anaerobic plays an important role in maintaining a stable environment during the stages of fermentation of waste. It was concluded that the theoretical calculation of energy production using the data inputs from municipal solid waste and the simulated result from MATLAB/Simulink is the same. The author in (KeChrist *et al,* 2020) investigated the technical advantage of biogas digester for cow dung comparing plastic biogas digester with concrete digester. In the authors view, he noted that dimensions and building materials for biogas digesters are crucial aspects to take into account during the design and fabrication process. The objective of the study offered a thorough assessment of the idea and construction of a 2.15 m^3 pilot plastic biogas digester for biogas production. To establish this, a design equation was modeled with a focus on the digester's shape, representing the digester's volume, its input and output chambers, and its cover plate. High-density polyethylene (HDPE) plastic was used to manufacture the digestion chamber of the biogas digester under investigation, while bricks and cement were used to build the intake and exit chambers. The study was inspired by several shortcomings, namely leaking linked to earlier designs. In the current research, a ventilation test was carried out and discovered that there were no leakage for the biogas inside the plastic bio-digester. The author concluded that HDPE's constructed bio-digester is cost effective and safer comparatively to concrete cement digesters.

In Malaysia, a research work done by an author in (Fadaeenejad *et al*, 2014) shown that traditional sources of power supply for electrification of remote areas had been by fossil fuel. Addition of solar energy as one of the renewable sources of energy has become very popular in the remote area. However, the paper shows that the renewable sources such as wind, hydro and biomass could make a hybrid system more cost- efficient and environmental friendly. It was also discovered that the combination of photovoltaic- wind – battery is cost effective hybrid energy systems for villages in Malaysia.

Ahmad *et al.* (2018) investigated techno economic feasibility of a hybrid grid tied micro grid system for the electrification of Kallar Kahar, Pakistan. The prospect of generating electricity through hybrid systems of wind, PV and biomass were evaluated

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Another author in (Ahmad *et al*, 2018) investigated techno economic feasibility of a hybrid grid tied micro grid system for the electrification of Kallar Kahar, Pakistan. The prospect of generating electricity through hybrid systems of wind, PV and biomass were evaluated using HOMER Pro software. Optimization and sensitivity analysis was carried out to ensure the robustness and cost effectiveness of the proposed hybrid micro grid system while residential and commercial sectors load demand profiles were considered in the design configuration. The result shows that hybrid system generates more than 50MW economically. In Ethopia, researchers in (Fikadu, 2020) accentuate that energy is one of the most essential resources needed in the world and it can be obtained from both renewable and non- renewable sources. In as much as the energy demands are growing, the search for alternative and sustainable renewable energy sources to replace the trendy fossil fuel supply, which is approaching extinction, is a must. The objective of the study is to examine the effects of temperature (°C), retention period (days), and the potential of animal wastes on the generation of biogas and the percentage of CH_4 in response to the study's parameters. The manures from cow dung, sheep and pig were employed in the investigation. The analysis used anaerobic batch digesters (plastic water bottles) with a total volume of 2000 ml served as the digester (bioreactor). The line for the glucose drip was attached to the lids of each digester while average temperature of digester was increased starting from the 6th to 10th day in cow dung and sheep manure. In this experiment, optimum time for best biogas yield was recorded and the results of the gas component shows the significant volume of methane (CH_4) in cow dung estimated to be 66.9 % followed by sheep manure 62.1 %. Cow dung was one of the best in producing biogas, while the sheep manure was medium, and pig manures are fewer producers as compared to others. The research also validated that enormous energy potential resides in the slaughterhouse waste (cow dung) which can be explored to produce energy.

Authors in (Wei *et a*l, 2021) investigated a hybrid solution of solar PV, diesel and biogas using HOMER software for simulation and optimization to provide the best solution for a reliable energy need of the grid connected village in Iran. The unstable economic condition of Iran necessitated the economic factors such as inflation rates and discount rates to be considered in the simulation to determine the optimal scenario for the village energy demand requirement. The author carried out a relative comparison to determine the optimal scenario, best location for the installation of solar PV panels whether as centralized plant or top –roof. The result of the analyses shows that with an inflation rate of 10 %, and a discount rate of 18 %, the best solution for the village energy demand includes a 63 kW photovoltaic,10 kW biogas generator and 15 kW diesel generator which could produce 0.193 $/kWh. Also with the changes in fuel price, interest rate and inflation rates within reasonable range of expected economic conditions for the project life time, the energy cost will vary from 0.085 to 0.238 $/kWh.

The researchers in (Kang *et al*, 2014) examined the economic feasibility of small combined heat and power (CHP) and the combined cycle (CC) systems using a 5 MW class of gas turbine fueled with biogas. The significance of this study lies in the fact that it was based on performance analysis of realistic hourly/ seasonal fluctuations of the CHP and CC performance. Economic indicators such as the annual gross margin, the net present value of the cash flow, and the payback period were computed using the investment and operating costs of the entire facility as well as the prices of electricity and heat. In the CHP system, two different heat demand patterns were contrasted. The following are the main findings. Sales of heat were shown to have a significant impact on the project's finances. Both CHP cases demonstrated a financial advantage over the CC system and the gas turbine-only system. The CHP system would be more advantageous than other options, which is another crucial discovery. The author in (Cvetkovic *et a*l, 2014)] investigated the potentials and status of biogas as energy source in the Republic of Serbia. The author was able to conclude that biogas is a sustainable and can provide green energy, a better environment. The biomass was sourced from slaughterhouses, agricultural crops etc. The work concluded that there is a great potential for biogas production in Serbia. The biogas production potential from agricultural crops directly cultivated for energy is 0.85 Mega tons of oil equivalent (Mtoe); the potential from livestock residues amounts to 94.13 ktoe; the potential from municipal solid

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waste (MSW) is 49.72 ktoe; the potential from slaughterhouse waste is 9.94 ktoe and potential from milk processing industry is 3.21 ktoe**.** In Ado-Ekiti, Nigeria, an investigation was done by reference (Sanni *et al*, 2021) which reveals that a well-planned renewable energy could meet the challenges of energy poverty; the author presented a hybrid solar PV/Diesel/ Biogas backup solution for unreliable grid electricity using the central abattoir at Ado Ekiti in South-West Nigeria as a case study. The locally available solar irradiance and potential of producing biogas from anaerobic digestion of slaughtered cattle paunch manure is proficient solution to embrace. The designed energy system complements an existing backup diesel generator system. In addition, comparative analysis reveals the Grid/PV/ Biogas system has reduced emissions when compared with Grid/PV/Diesel system and this proffered a good solution for unreliable grid network.

In the same view, meeting the water and lighting needs of some selected abattoirs in Ibadan Nigeria through the application of solar PV was attempted by researchers in (Ayodele *et al*,2018), the quantity of water and the amount of energy consumed for the lightings loads of the abattoir was obtained by direct inspection of the study location, hybrid of solar PV-BATT was employed for the pumping, although the approach appeared promising, but the levelised cost of energy was reported to be higher, due to the cost of battery since the battery has to be replaced due to heavy current drawn by the induction motor, this alone limit the attractiveness of this approach.

The investigation conducted in the previous section and the summary in Table 2 demonstrated that relatively few works have been reported on renewable energy generating sources; some of them have presented the idea of biomass and bio-energy conversion processes and resources review, while the majority have presented the design of energy systems for remote communities using a hybrid renewable energy system that includes biomass fuel resource based on the technical and economic (TE) analysis. Some of the research studies considered technical, economic, environmental, political, and social (TEEPS) analysis methodologies, other research studies have employed the technical, economic, and environmental (TEE) analytical technique. Due to the enormous availability of biomass resources from the slaughtered cows, research into alternative energy provision for slaughterhouses has lagged. This area of interest highlights the gap that must be filled from the review of particular studies examined globally. Additionally, it was evident from the evaluated work's shortcomings that the reliability and sensitivity of the hybrid energy system under discussion up to this point had not been adequately and convincingly addressed. The issue of reliability is evidently seen as a large number of many pilot projects expected to enjoy a life span 20-25 years, and do not live up to life expectant especially in Sub -Saharan African countries. Many of such projects died briefly after initiation and lots died briefly after few years of commissioning. The following highlights are essential to mitigating key issues with reliability and sensitivity concerns of hybrid energy systems;

i) **Sustainable and Robust Design-** The robustness of any energy design is a key factor that ensures the energy system designed is able to meet the demand or load which is expected to serve. There are certain indices which indicate the sustainability of the system such as Lost of Energy Probability (LOEP) (Khan et al, 2013). This is a statistical data dependent which determines the unmet load or unserved load. When the system is able to sufficiently meet or cater for the unmet Load, then the reliability is improved and the system can then be regarded as sustainable with all the cost variables comfortably lying within the profit margin. The deficiency in the resources causes at a certain period in a zone may affect energy production. Therefore, the energy which is expected not to be supplied to meet demand needs is regarded as expected energy not supply. This determines the reliability index of the system.

ii) **Hybridization of energy sources** is another viable way of achieving reliability of energy generating system. The natural intermittence of renewable resources such as solar resources in terms of irradiation and wind speed which invariably affect the reliability of the renewable energy source can be remedied by using different configuration of hybrid system. In fact, this has been well treated by researchers. The real essence of this is to make provisions for some certain controls that are beyond human. For instance the times where the sun

Table 2: Overview of the reviewed work done in biomass exploration and exploitation

Author	Area of Application	Hybrid configuration	Tools	Performance metrics	Gaps
Bambokela *et al (*2022)	Rural electrification Botswana, Palapye	Biogas/PV	HOMER		Penetration of the energy source was not captured
Al-Ghussain *et al* (2021)	Electricity for the Middle East University of Northern Cyprus campus	PV/Wind/Biomass	HOMER	NPV, LCOE	No detail reliability was done.
Francis B. Agyenim (2020)	Rural Electrification, Ghana	PV/ Biogas.	Multicriteria Analysis (MCA)	CO2 emission, NPV, CBA, IRR	Scanty economic analyses. Reliability is not covered. Penetration of each energy source to achieve optimization was not captured
Rimong et al. (2020)	Rural electrification, Parit- Raja, India	Biogas/diesel gen	MATLAB/ Simulink	Energy Output, CO_2	The reliability and Sensitivity - changes in the input resources not considered. Penetration of the biogas.
Sanni *et al* (2020)	Backup power for Central Ado ekiti abattoir	PV/Grid/Biogas	HOMER	LCOE, NPV and CO_2 emission	No though reliability done
Fitsum *et al* (2020)[	Electric Energy for Industry	PV/Biomass	Matlab and TRNSYS	LCOE	Penetration of each source not done
Alibakhsh *et al* (2019)	Rural Electrification of a Village, Iran	PV/DEG/ Biogas	HOMER	CO_2 COE Sensitivity NPC	Reliability analyses of the system not covered
Araoye *et al* (2018)	Electrification of community Ajaba, Osun State, Nigeria	PV/Biogas	Matlab	Volume of biogas, Energy produced	The sensitivity of the system was not investigated
Jameed *et al (*2018)	Rural electrification, Kallar-Kahar, Pakistan	PV/Wind/Biomass	HOMER Pro	LCOE, NPV, CO_2 emission	Sensitivity analyses were not done and the reliability system
Eteiba *et al* (2018)	Rural electrification/ techno-economic study of an off-grid	PV/Biomass/BESS	Metaheuristic algorithms	NPC, LCOE, LPSP, Percentage of excess energy.	There was no elaborate work on the reliability and sensitivity of the hybrid system
Gonzalez *et al (*2014)	Energy challenge of Iberian company in Spain	Biogas/PV		CO_2 Emission, NPC, IRR PBP, COP	The reliability and sensitivity of the system were not detailed

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may not shine leading to low irradiation, low wind profile speed etc, at such times, the reliability of 100 % of wind turbine or solar will be threatened.

iii) **Average Capacity Factor**: The capacity factor also evaluate the reliability of energy generating systems by measuring or evaluating how often a plant is on operation at maximum power. A 100 % plant capacity shows that the energy-generating system is producing power all of the time. It is expressed as a percentage and calculated by dividing the actual unit electricity output by the maximum possible output. This ratio is important because it indicates how fully a unit's capacity is used.

iv**) Demand Response system**: Demand response has significant effect on reliability of energy supply by regulating the demand and peak load at the end users side. The customers are encouraged to reduce their energy demand based on the integrated energy model with attached incentives (Mohammad &Mishra, 2018; Aalami et al, 2010)

v) Energy security and Disparity of use: Another factor affecting reliability of energy which many researchers have not considered is energy security and disparity of use. The reliability of energy is a function of its availability, Affordability, Accessibility and Acceptability. With current crisis of Russia invading Ukraine and other warring nations of the world, the security of gas or energy resources will be effected which will invariably impacts the availability of such energy. Therefore the political instability of producers' countries will affect the reliability of the concerned energy production of such producer countries. An option to improve reliability in such scenarios may be to do extensive sensitivity analyses and uncertainty evaluations of such energy sources (Masson et al, 2014)

4. Prospects and challenges of application of biogas in sub-Africa

An in-depth investigation has been made regarding the work done so far on the extraction techniques, utilization, and adoption of biomass technologies across some parts of the globe. As seen in Table 2, there are a lot of Feasibility studies on the utilization of biogas from biomass and even its hybridization with other renewable energy resources. However, there is little or no pilot project(s) reported in the examined papers which span from 2013 to 2023. There is therefore the need to critical examine factors limiting the implementation, the likely prospects as well as the challenges confronting massive deployment of biogas from biomass resources especially the wastes from slaughterhouses/abattoir.

4.1 The challenges

As sustainable as biogas extraction from slaughterhouse/abattoirs waste is, the process can be regarded as close loop system- it is a recycled process- yet there are a lots of challenges confronting its exploitation and exploration. A few of these challenges are as listed;

i) Water content**:** Highly moisturized contents of biomass are not suitable as feedstock for conventional thermo-chemical conversion technologies such as gasification and pyrolysis. Biomass with high moisture will reduce the effectiveness of conversion processes. Moisture in raw biomass materials is also undesired because fuel produced from these materials can contain moisture and these fuels which are characterized by the presence of high moisture contents cannot burn easily. The drawbacks of high moisture contents can be mostly solved by compressing the biomass material for more uniform properties through a process called densification (Sibel 2019).

ii) Low-density nature: naturally, the density of biogas is low and it has a direct effect on the heating value. This is a major challenge that differentiates biogas from conventional natural gases and LPG (Yadav *et al*, 2013)

iii) Variability nature of biomass: Energy provision must be continuous and consistence but the fluctuation of biomass resources is a big challenge for the continuous production of energy from biomass. The variability in the ash content and lignin between woody material and herbaceous feed-stock affect the conversion efficiency and reduces the bio-fuel yield (Williams *et al,* 2016) .

iv) Competition with food supply: The crops used mostly for biomass are equally good for human consumption, the use of maize, sugarcane, wheat, cassava etc posed a big challenge and insecurity. The utilization of such crops for energy production creates a threat to the well-being of man whereas the need to grow more crops for food to mitigate the rising prices of food (Negash & Swinnen, 2013).

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v) Technical know-how: Most of the conversion technologies deployed in transformation of biomass to bio-fuel or energy production are imported. These technologies have to be properly transferred and localized for effective utilization in underdeveloped countries (Benti et al, 2021)

vi) Level of awareness: Another challenge to the exploitation and exploration of biomass energy is awareness. The awareness has not really attained a generic status, many are not aware about the good potentials in biomass. Government and policy makers must create comprehensive biomass policy to ensure and encourage the exploration of biomass energy. As well as establishing institutional base support on research and deployment (Beyene et al, 2018).

4.2 The prospects

Despite the challenges enumerated above, the prospects embedded in the exploitation and exploration of biomass for biofuel or the production of energy are enormous. Quite a few of these prospects are briefly discussed below:

1) CO_2 emission: The use of biogas as a source of energy is freedom from carbon dioxide emission thereby reducing the consequent impact of conventional fossil fuels on the climate.

2) Food value chain: The digestate extracted from the biochemical process of conversion of biomass to biogas produces products which in-turn can be used as bio-fertilizers for the enhancement of the production of agricultural produce.

3) Cost of Energy: The overall analysis of cost metrics of energy (kWh) has shown that biogas fueled energy systems are cheaper and cost-effective as compared to other conventional energy production.

4) Employability: The employment issue and engagement of various strata of skills are possible when biomass technologies are exploited and explored. The unemployment scale of the nation's population draws down, enhancing the condition of the people when gainfully employed in such biomass facilities and establishments.

5) Transportation Fuel: Research on biofuels has focused on biogas as the best alternative for gasoline fuel. The over-dependence of petroleum and its associates can be mitigated when biomass energy is explored and transformed to fuel vehicle engines.

4.3 Future road-maps in the exploitation and exploration of bio-fuel from biomass

The future of biofuel exploitation and exploration from biomass is noteworthy as it will proffer so many benefits to the global energy sector and create wider opportunities for accessibility and utilization, thus improving the human development index as a result of improved communication, agricultural activities, education, health service, commerce and trade that depend on the availability of sustainable and reliable energy. However, the future road-map of bio-fuel exploration from biomass will drive several opportunities. Quite a few numbers of these opportunities are enumerated below:

1) Transport Sector: Bio-fuel will particularly replace the fossil fuels which have dominated the sector with their attendant challenges on the environment. A well-treated Bio-fuel will be used in long-distance trucks, shipping and as aviation fuel hence influencing the trends of global transport fuel.

2) Rural electrification: Extension of grid networks to remote areas is associated with several challenges ranging from the cost of implementation, structures, labour, terrain, etc, bio-fuel stands as a future hope for such rural areas deficient in accessibility to sustainable electricity. In the near future, there will be more of a distributed generation network to cater for the energy poverty in such remote locations.

3) Portable digester/modular digester advent: Bio-fuel especially biogas has the capacity to replace the conventional NLG gas use for heating and cooking so exploitation and exploration will definitely usher more scalable and portable cooking gas using biogas.

4) Reduction of carbon footprint: The exploitation and exploration of biofuel and utilization will create enhancement to reduce carbon emissions in the future, therefore, greenhouse emissions will be mitigated when

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biofuel is explored and this will proportionately impact the carbon footprint.

5) Institutional Research base: biofuel will trigger more establishment of an institutional base for research and development; this will encourage more scientific/technical developments in the utilization and deployment of biomass and biofuel.

6) Global Economic: There will be an economic improvement if biofuel is explored and utilized it will impact the global economy and boost trade among the continents of the world. The cost of energy and economic scale of preference will favour biofuel because of its intrinsic advantages.

5. Conclusion

Presented in this paper is a detail exploration and exploitation of bio-fuel from biomass with an emphasis on conversion of wastes from slaughterhouses/abattoirs to sustainable energy generation. Relevant published research papers across various countries of the world were carefully sampled and reviewed and the summary of the contributions of the existing studies was carefully examined, and new gaps were identified. The paper makes efforts to analyze the approaches for mitigating issues regarding reliability and sensitivity in the design of multi-energy systems that can be used concurrently with biomass energy resources. The challenges limiting the utilization of biomass from slaughter house waste were also carefully identified, and the prospects with the adoption, utilization and mass commercialization of biomass from abattoirs were comprehensively discussed while the future road-map for utilization of slaughterhouse waste for the generation of sustainable energy was comprehensively itemized. Conclusively energy generation form slaughterhouse waste is sustainable, scalable and adaptable for meeting the energy needs of the abattoir thereby contributing to a sustainable clean environment void of environmental hazards.

References

Aalami H., Moghaddam, M and Yousef, G (2010).Demand response modeling considering Interruptible/Curtailable loads and capacity market pro grams, *Applied Energy,* 87(1): 243-250, accessed on 7th June, 2023.

Achinas, S., Achinas, V and Euverink, G (2020). Microbiology and biochemistry of anaerobic digesters overview, Chapter 2, *Elsevier, 2: 17-26*

Agyenim, F., Dzamboe, P., Mohammed, M., Bawakyillenuo, S., Okrofu, R., Decker, E., Agyemang, V and Nyarko, E (2020). Powering communities using hybrid solar–biogas in Ghana, a feasibility study, *Environmental Technology & Innovation, 19: 100837.*

Ahmad J., Imran M., Khalid A., Iqbal W, Rehan S., Ashraf, Muhammad Adnan, Syed Farooq Ali, Khawar Siddique Khokhar, (2018).Techno economic analysis of a wind-photovoltaic-biomass hybrid renewable energy system for rural electrification: A case study of Kallar Kahar. *Energy,* 148: 208-234.

Al-Ghussain, L., Ahmad,A., Bubaker, A and Mohamed, M (2021). An intergrated photovoltaic / wind / biomass and hybrid energy storage system towards 100% renewable energy microgrids in university campus-es. *Sustainable Energy Technologies and Assesments,* 46:101273

Alibakhsh, K., Parisa, R., Mohammad, A and Wei-Mon,Y(2019). Optimal design and technical analysis of a grid-connected hybrid photovoltaic/diesel/biogas under different economic conditions: A case study, *Energy Conversion and Management,* 198: 111810.

Anna, D., Tatiana, R and Rupert,J (2022).Implementing circular economy strategies during product development, Resources, *Conservation and Recycling,* 184:106344.

Araoye, T., Mgbachi, C., Okelola, M and

https://dx.doi.org/10.4314/aujst.v5i2.6

Ajenikoko, G (2018). A Comparative Analysis of Renewable Energy Using Biogas and Solar Photovoltaic Systems:A Case Study of Ajaba, in Osun State. *10.13140/ RG.2.2.23702.80969*.

Ayodele T.R., Ogunjuyigbe A.O and Adeniran, A (2018): Evaluation of solar powered water pumping system: the case study of three selected Abattoirs in Ibadan, Nigeria, *International Journal of Sustainable Engineering*,12 (1):58-69.

Bambokela, J., Belaid, M., Muzenda, E and Nhubu, T(2022). Developing a Pilot Biogas- Solar PV System for Farming Communities in Botswana: Case of Palapye,

Benti, N.E., Gurmesa, G.S., Argaw, T.,Aneseyee, A.B.,Gunta, S., Kassahun,G.B.,Aga, G.S and Asfaw A.A (2021). The current status, challenges and prospects of using biomass energy in Ethiopia. *Biotechnol Biofuels, 14: 209, https://doi.org/10.1186/ s13068-021-02060-3*

Bergman, P.C.A (2005). Combined Torrefaction and Pelletisation: The TOP Process; ECN-C-05-073; 2005, Available online: https://publications.tno.nl/publication/34628560/S7JA61/c0073.pdf (accessed on 20 June 11th, 2023)

Beyene, G.E., Kumie, A., Edwards, Rand Troncoso, K (2018). Opportunities for transition to clean household energy in Ethiopia: Application of the WHO Household Energy Assessment Rapid Tool (HERT). *World Health Organization; 2018. Available at:https://apps.who.int/iris/ handle/10665/311280. Accessed on: 29th July,2023.*

Biomass for Bioenergy, *IntechOpen, 1, 2019, https://doi.org/10.5772/ intechopen.83752*

Blimpo, M.P., Cosgrove-Davies and Malcolm (2019). Electricity access in sub-saharan africa: uptake, reliability, and complementary factors for economic impact. Africa Develop-mentForum, Washington,DC:WorldBank. Availableat:https://openknowledge.worldbank.org/ handle/10986/31333.

Cvetković,S., Radoičić, T., Vukadinović,B and Kijevčanin,M (2014).Potentials and status of biogas as energy source in the Republic of Serbia, *Renewable and Sustainable Energy Reviews*, 3: 407-416*,*

Eteiba, M., Barakat, S., Samy, M and Wahba, W (2018).Optimization of an Off-Grid PV/Biomass Hybrid System with Different Battery Technologies. *Sustainable Cities and Society*. 40. 10.1016/ j.scs.2018.01.012.

Fadaeenejad, M., Mohd, R., Mohd, A., AbKadir, M., Hizam, H (2014).Assessment of hybrid renewable power sources for rural electrification in Malaysia. *Renewable and Sustainable Energy Reviews*,30. 299–305.

Fikadu, K.G (2020).Evaluating the Potential of Domestic Animal Manure for Biogas Production in Ethiopia", *Journal of Energy,2020:1-4. https://doi.org/10.1155/2020/8815484*

Fitsum, B., Ramchandra, B and Mengesha, M (2021).Design Optimizations of a hybrid solar–biomass plant to sustainably supply energy to industry: Methodology and case study, *Energy, 220: 119736*.

Francis, B., Pax D., Mutala, M., Simon, B., Raymond, O, Edward, D., Victor, K and Eric, H (2020).Powering communities using hybrid solar–biogas in Ghana, a feasibility study, *Environmental Technology & Innovation,19:(2020), 100837*

Garba, A (2020). Biomass conversion technologies for bio-energy

https://dx.doi.org/10.4314/aujst.v5i2.6

generation: An introduction, biotechnological applications of biomass. *IntechOpen, DOI: 10.5772/ intechopen.93669.*

González-González, A., Collares-Pereira, M.,, Cuadros,F and Fartaria,T (2014).Energy self-sufficiency through hybridization of biogas and photovoltaic solar energy: an application for an Iberian pig slaughterhouse. *Journal of Cleaner Production,* 65:318-323

Hitzl, M., Corma Canós, A., Pomares Garcia, F., Renz, M.(2015).The hydrothermal carbonization (HTC) plant as a decentral biorefinery for wet biomass. *Catalysis Today*, 257: 154–159.

HOMER Pro Microgrid Analysis Tool x64 3.10.3(Pro Edition).

Jameel, A., Muhammad, I., Abdullah, K., Waseem, I., Syed, R.A., Muhammad, A., Syed F.A and Khawar,S (2018). Techno economic analysis of a wind-photovoltaic-biomass hybrid renewable energy system for rural electrification: A case study of Kallar Kahar, *Energy,* 148: 208-234.

Kang,J., Kang,D., Kim, T., and Hur,K (2014). Comparative economic analysis of gas turbine-based power generation and combined heat and power systems using biogas fuel, *Energy, 67: 309-318*.

KeChrist, O., Sampson, M., Edson, L.M., Golden, M and Nwabunwanne, N (2020). Design and fabrication of a plastic biogas digester for the production of biogas from cow dung. *Journal of Engineering*,1-11.

Khan, S., Paliwal, V., Pandey, V and Kumar, V (2015). Biomass as renewable energy. *International Advanced Research Journal in Science, Engineering and Technology* 2: (2015).

Khan,K.R., Abou-Arkoub, A.A and Newtown, M.J (2013). Evaluation of loss of load probability and expected energy generation in multi-area interconnected systems with wind generating units, *2013 IEEE International Conference on Smart Energy Grid Engineering (SEGE)*, Oshawa, ON, Canada, 2013: 1-8, *doi: 10.1109/SEGE.2013.6707907*.

Lazarov, V., Notton,G., Zarkov, Z and Bochev, I (2005). Hybrid power systems with renewable energy sources – types, structures, trends for research and development. *Proc of Intl Conf*.

Li, J., Liu, J., You, Y and Zhang, A. (2022). Research progress on the energy conversion efficiency of wind turbines. *Highlights in Science, Engineering and Technology*, 3:182– 193.

Lin, J.H, Wu, Y.K., and Lin, H.J (2016). Successful experience of renewable energy development in several offshore islands. Energy Procedia, 100: 8-13.

Masson, A., Johansson, B and Nilsson, L (2014). Assessing energy security: an Overview of commonly used technologies, *Energy,* 73: 1-4.

Mohammad, N and Mishra, Y (2018). Coordination of wind generation and demand response to minimize operation cost in day-ahead electricity markets using a bi-level optimization framework. *IET Gener Transm Distrib* ,12(16): 3793–802.

Negash, M., and Swinnen , J (2013). Biofuels and food security, micro-evidence from Ethiopia. Energy Policy. 61: 963–76.

Olabode O.E, Ajewole T.O., Okakwu I.K., Alayande A.S and Akinyele D.O (2021). Hybrid power systems for off-grid locations: A comprehensive review of design technologies, applications and future trends. *Scientific African*. 13(2021):e00884 *Paper.5.10.4271/2013-26-0012*

Procedia Computer Science, 200:1593-1604.

Renewable energy fact sheet: wind turbines. Availabe online at: https://www.epa.gov/sites/default/files/201908/documents/wind_turbines_fact_sheet_p100il8k.pdf.

Rimong, C and Jumaat, S (2021). Modeling and analysis of electrical generating from biogas produced by municipal solid waste at Parit Raja. *Materials Today: Proceedings. 41. 10.1016/j.matpr.2020.11.1017.*

Rimong, C and Jumaat, S(2021). Modeling and analysis of electrical generating from biogas produced by municipal solid waste at Parit Raja. *Materials Today: Proceedings. 41. 10.1016/j.matpr.2020.11.1017.*

Russell, N.J and Fukunaga,N (1990). A comparison of thermal adaptation of membrane lipids in psychrophilic and thermophilic bacteria, *FEMS Microbiology Letters*, 75(2-3): 171-182

Sanni, O.S., Oricha, J.O., Oyewole,T.O and Bawonda, F.I (2021). Analysis of backup power supply for the unreliable grid using hybrid solar PV/diesel/biogas system. *Energy 227, 120506.*

Sibel, I (2019). Challenges of Biomass Utilization for Bio-fuels,

The New World Enclopedaedia Tidal Power, The New World Encyclopedia, 2020,

Available online at https://www.newworldency clopedia.org/entry/ Tidal_power. Accessed on 5th April 2023.

United States Environmental Protection Agency August (2013).

Urmee, T and Md, A (2016). Social, cultural and political dimensions of off-grid renewable energy progams in developing countries. *Renewable Energy*, 93:159-167

Valerio P., Francesco P., Marco S., Laura T., Nour N and Angelo, C. (2018). Environmental impact of biogas: a short review of current knowledge. *Journal of Environmental Science and Health,* Part A, 53(10): 899-906.

Vidyanandan, K.V. (2017).An overview of factors affecting the performance of solar PV systems. *Energy Scan,* 27:2-8

Wei, H., Li, T., Lei, H., Yasong, S., Pietro, E and Jinyue, Y(2021). Optimal analysis of a hybrid renewable power system for a remote island, *Renewable Energy,* 179: 96-104,

Williams, L., Westover, T., Emerson, R., Tumuluru, J. S and Li, C (2016). Sources of biomass feedstock variability and the potential impact on biofuels production. *Bio Energy Research. 9. 10.1007/s12155-015-9694-y*

Yadav, S. D., Kumar, B., and Thipse, S. S. (2013). Characteristics of biogas operated au tomotive SI engine to reduce exhaust emission for green development. *SAE Technical*

Yimen, N., Hamandjoda,O., Meva'a,L., Bénoît, N and Nganhou, J (2018). Analyzing of a Photovoltaic/Wind/Biogas/Pumped-Hydro Off-Grid Hybrid System for Rural Electrification in Sub-Saharan Africa—Case Study of Djoundé in Northern Cameroon. *Energies. 11: 2644. 10.3390/en11102644.*

Zhang, T., Shi, X., Zhang D and Xiao J (2019). Socio-economic development and electricity access in developing economies: A long-run model averaging approach. *Energy Policy,* 132*:* 223-231

https://dx.doi.org/10.4314/aujst.v5i2.6