Chapter

Biowastes as a Potential Energy Source in Africa

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Abstract

High population and industrialization have brought the need for a reliable and sustainable source of energy and protection of the environment. Although Africa has a low energy consumption capacity (3.4% of the global share in 2019), its high population growth rate and industrialization predict high energy demand in the future. Reliable and available energy resources are required to protect the environment and create energy dependency. Despite Africa's low energy consumption capacity (3.4% of global consumption in 2019), its rapid population growth rate and industrialization indicate future significant energy demand. The current high production of biowastes with high energy content and their low utilization provides an opportunity for energy dependency, crop value addition, creation of jobs, and protection of the environment. The chapter has identified that the African population of 1.203 billion in 2017 consumed 928 Mtoe of energy and this demand is expected to increase in years to come. The energy mix has been identified to depend on fossil fuels with little consideration of biowastes. The biowaste is reported to contain 20.1 TWh in 2025. Biowaste is currently underutilized, and there are few conversion methods available. Government and non-government investments have been reported to be making efforts to improve bioenergy and biowaste usage. The prevailing challenges have been low proven technologies, poor energy policy, low population knowledge, and poor investments. Biowastes use can be increased when environmental laws and legislation are tightened, energy policy strengthened and enforced, cheap and appropriate technologies are introduced, and the population Education is provided. It is expected that when biowastes are well utilized, energy will be available even in disadvantaged (remote) areas at an affordable price for the developing continent of Africa.

Keywords: municipal solid wastes, crop and forest residues, biowaste, renewable energy

1. Introduction

Energy has been a critical issue in most African countries where most of their populations are deprived of it. With the current population growth, the situation is alarming and needs serious intervention to rescue. It is predicted that one-in-two people added to the global population between 2019 and 2040 will be African. In 2025, Africa's population is predicted to exceed that of both India and China [1]. This increase in the population, combined with an increase in purchasing power, will put additional strain on the existing energy supply, resulting in a significant increase in energy demand. With the current trend of industrialization and population growth, the energy demand is expected to rise and put high pressure on the current fossil fuel resources. In 2018, Africa's energy demand was estimated at 700 TWh of which 70% was consumed by south and northern countries. This energy consumption is forecasted to reach 1600-2300 TWh by 2040 [1]. Such a huge increase in energy demand requires African countries to be prepared for a sustainable solution. The globe's energy resources have mainly been dominated by fossil fuels, which cover around 81% of the total energy supply in 2018 [2]. High dependency on fossil fuels not only brings uncertainty but also leads to global warming and environmental pollution. Therefore, the appropriate use of fossil fuels and the introduction of renewable energy technologies are required for sustainable energy and the environment.

The use of some renewables may be associated with high cost and occurrence, but bioenergy sources are expected to be the most promising option for meeting future energy demands [3]. Its conversion cost is expected to be lowered due to the availability of biomass, low cost, and high energy demand. Due to the global goal to departing from fossil fuels, the incorporation of bioenergy in energy generation has gained attention, mostly in developed countries. Although Africa is blessed with biomass, its use in electricity generation is still low, but expectations in the future are high [1]. The biomass potential is expected to continue to increase due to available cultivatable and fertile land, unutilized wastes, and cheap and simple conversion methods. Also, the utilization of biomass will continue to grow due to initiatives of African countries to intensify energy security. The African Union has the 2063 agenda that aims to have modern, efficient, reliable, and cost-effective renewable energy for all households, businesses, industries, and institutions [4]. This agenda has gained support with investments, among them being the African Development bank since 2016 [4]. High investment of USD $43-55 billion per year compared to USD $ 8-9.2 billion that is currently invested, will continue to stimulate incorporation of renewable energy, among them being biomass. To achieve this goal, understanding the type, quality, quantity, and distribution is necessary.

Although utilization of fresh biomass for energy has a great potential in unlocking energy demand challenges in Africa, it tends to bring competition for land with food crop cultivation. Furthermore, it leads to high utilization of fertilizers and high investment costs. To reduce the dependency of fresh biomass, alternative biomass sources should be considered. The possible sources that have gained attention not only for energy generation, but also for environmental concerns, are; crops and forest residue, non-edible biomass, animal wastes, and Municipal Solid Wastes (MSW). The application of biowaste for energy generation will not only solve the forecasted energy demand but also improve waste management in Africa. Africa is faced with ever-increasing waste management and utilization challenges. Among the challenges that hinder biowastes utilization are poor management, weak legislation, lack of enforcement, low public awareness, corruption, conflict and political instability. While the amount of waste produced in Africa is minimal in comparison to developed nations, waste mismanagement in Africa is already having an impact on human and environmental health [5]. It is estimated that an additional USD$8 billion could be injected into the African economy each year by just diverting waste away from dumpsites or landfills for reuse, recycling, and recovery [5].

Converting biomass waste to energy necessitates a thorough understanding of the potential type and availability of waste feedstock, as well as the potential application of the chosen technology. The knowledge of energy potential and possible appropriate conversion technology affects investors and policymakers. Therefore, there is a need to expose the huge potential of biowaste as an energy source for Africa to shift the alignment from fossil fuels to biowaste energy for sustainable energy and the environment. This chapter mainly focused on biowastes as a potential energy source in Africa. It describes the potential biowaste sources, such as crop and forest residue, MSW, and animal waste, and the potential energy present. Different technologies available for converting have also been discussed. Finally, this chapter proposes a way forward towards sustainable biowaste energy generation for Africa.

2. Energy status and challenges in Africa

Energies in Africa change, but not uniformly. Although new oil and gas discoveries are now accompanying the expansion of renewable energy generation, yet Africa as a whole is straightly above Germany as a country in electricity generation and consumption [6, 7]. The mean energy consumption per capita in most African countries is well below the world average and is equivalent to that of India. Biomass energy is currently Africa's most important source of energy, supplying 47.2% of primary energy demand and more than half of total energy consumption [8]. In 2017, Africa had a total primary energy supply (TPES) of 1,148,475 Mtoe in which biomass, oil, natural gas, and coal contributed 37.93, 37.99, 15.3, and 12.7%, respectively [7]. Of all the energy available, Africa imported 184,768 Mtoe (16%). Transportation, household, and industrial consumers, share were about 70.1, 8.9, and 8.5%, respectively [7]. This indicates that transportation consumes a large percentage of energy, with 29,461 Mtoe imported. Furthermore, in 2017, electricity that was available for use was 1.71% of TPES, which amounted to 1,058.74 TWh from thermal conversion of biomass, natural gas, and coal at 78.55%. It was noted also in the same year, the total energy supplied was 928.051 Mtoe, which is equivalent to 123.75% energy dependency. The energy consumed was sourced from biomass, crude oil and natural gas at percentage shares of 47, 11.3, and 13, respectively.

There has been an increase in electrical energy consumption worldwide from 10,897.94 to 24,738.92 TWh from 1990 to 2018, while Africa increased from 286.04 to 722.84TWh in the same period [9]. Global primary consumption for the same period increased from 83,830 to 123,695 TWh, meaning the electricity consumption share changed from 13–20%. This increase has been attributed to the development and an increase in population. This means that the increase in electricity in the energy mix in Africa should be increased. In 2017, the electricity share was only 9% [7], meaning electricity consumption is below the global average. Globally, energy comes from a range of sources, ranging from biomass, nuclear, fossil, and other renewables. The main source of energy has been fossil fuels.

Biomass has emerged as a viable and sustainable renewable energy source, with an 11% global contribution. According to reports, biomass provided 95% of world heat production in 2019 [2] and generated 637 TWh of electricity. Biomass also accounted for 3% of worldwide transportation energy. Domestic consumption accounts for roughly 85% of its contribution [2]. By 2030, it is estimated that 720-920 million people in Sub-Saharan Africa will rely on biomass and 2.7 billion people worldwide. According to UN Environment Programme research, 65% of countries in Sub-Saharan Africa will still rely on biomass in 2050 [10]. This is the indication that biomass is the main energy source and should well be used efficiently and sustainably.

2.1 Energy mix in Africa

Africa has low energy consumption per person when compared to other countries, falling below the global average of 2 toe. For example, in 2018, with except

South Africa, the consumption was below 0.8 toe, with sub-Sahara Africa having lower than 0.4 toe [1]. Energy is derived from a variety of sources, including coal, oil, gas, nuclear power, biomass, and other renewables. **Figure 1** depicts the energy mix by energy source. Biomass is still the main source of primary energy mostly used in cooking. Except north Africa, biomass contributes around 60% by which no any part of the global depends [1]. In Sub-Saharan Africa, for example, biomass consumption is currently above 80% [4]. Oil is the next energy source in Africa after biomass. In 2018, oil consumption was over 4 million barrels per day, with 60% of that consumed in transportation and diesel used as a generator backup. **Figure 2** depicts energy consumption in Sub-Saharan Africa by sector in 2017. Household is the main consumer of energy of about 64% and mostly depend on biomass.

Africa continues to rely on fossil fuels for electrical generation (92%); oil (42%), natural gas (28%), coal (22%), hydropower (6%), nuclear (1%), and other renewable energy (1%). **Figure 3** shows electricity production sources through thermal heat technology. The resources are limited, and the deposits will be depleted as quickly as possible as the population grows. Since fossil sources do not rejuvenate, the sustainability of them is in compromise. To solve dependency of fossil fuel, Africa should focus on other resources. Apart from biomass, she still has other potentials such as; 10 TW of solar, 350 GW of hydro, 110 GW of wind, and 15 GW of geothermal energy. Due to high investment costs and distribution of other renewable resources, biomass is and will continue to be a significant source of energy due to wide distribution, modular and simple conversion technologies, and appropriate production land. The population growth leads to large production of biowastes. Due to high increase in energy demand, there comes a need to develop the utilization process of wastes for energy generation. Therefore, in future,

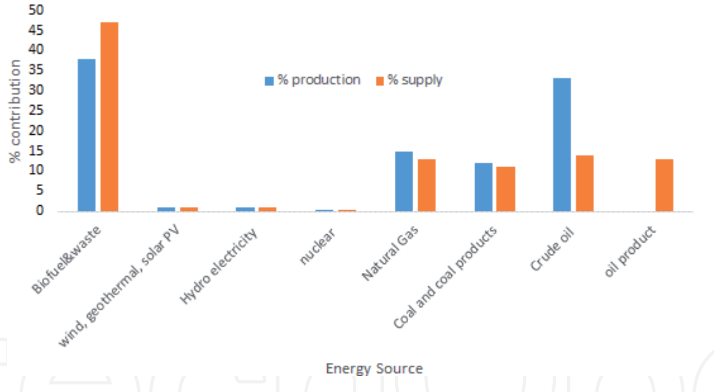

Figure 1.
% share of energy sources 2017 [7].

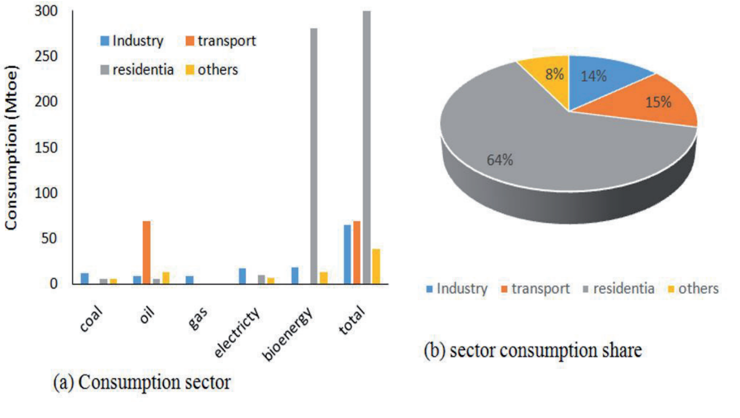

Figure 2.
Energy source consumption by sector in sub-Sahara Africa 2018 [1].

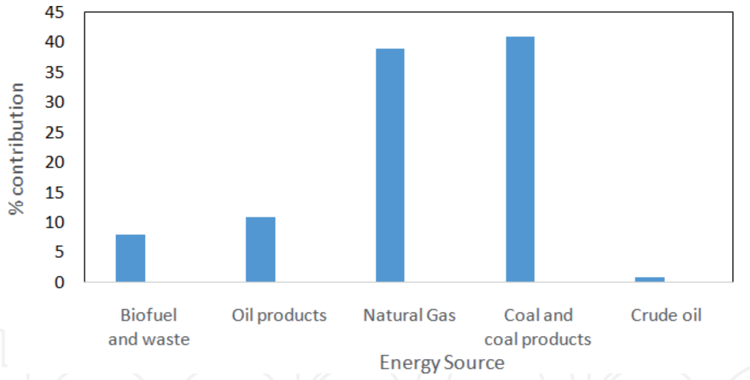

Figure 3.
Contribution of energy sources in electricity production [7].

biowastes are expected to contribute highly to the energy mix and hence lead to energy and environmental sustainability.

2.2 Challenges of energy sources and stability

As reported earlier, Africa energy consumption per capital is the lowest in the world. But also it was stated that the population and development in the future will lead to high energy demand. From earlier analysis, still Africa relies on fossil fuel in electricity generation and biomass in other uses. Transport sector has been identified to consume 64% of total energy consumed. Unfortunately, the production of transportation energy is still low with large importation of oil. The utilization of electricity and natural gas in the transportation sector is still low. This implies that much of transportation energy source is dependent on global oil stability. Lack of local and alternative sources puts uncertainty of both energy production and supply. Unluckily, available renewable sources are not well utilized due to obstacles such as investments. These entire situations put a big challenge of energy stability.

It has been also identified that biomass is the main source of energy. Biomass sources such as forest have challenges on utilization when it comes to deforestation. The study report in 2018 has shown that East and West Africa deforestation since 1900 was 93 and 83%, respectively [11]. Thus, the sustainability of biomass as the source of energy is hindered by deforestation. Furthermore, the competition of land and food crops still hinder the sustainability of biomass. In case of biowaste utilization, high investment, knowledge, and technology make them unfavorable resources. Also the poor governmental policy on sourcing local sources are also a challenge. To avoid instability of energy sources from external situation such as environmental movement and global oil market, Africa should find suitable sources. The dependency of virgin biomass and competition of area for food and energy crops, utilization of less used energy resources should be implemented. The policy and investment should be the priority in utilizing sources that lead to sustainable energy and environment.

Thus, to have energy and environmental stability, the use of biowastes is important. To implement biomass challenges such as variation of composition, large distribution, low energy density and poor energy conversion, appropriate technology should be implemented (**Figure 3**).

3. Status of biowastes potentials and utilization in Africa

The global biowastes production is currently estimated to be over 140 Gt per annum [12]. On global scale, more than 2 Gt of garbage is burned inefficiently,

Africa sub-region	Crop residue (Mt)[1]	Wood residue (m^3)	Animal wastes (Mt)[2]
Eastern Africa	77	114 465	841
Middle Africa	22	16 000	266
Northern Africa	59	121 000	334
Southern Africa	15	55 380	88
Western Africa	101	712 200	565
Total	274	1 019 045	2094
World	3714	231 773 138	8507
% to globe	7.4	0.44	25

[1]*Estimation by FAO for crops Barley, Beans, Maize, Millet, Oats, Potatoes, Rice, Paddy, Rayne, sorghum, Soybeans, Wheat using FAO TIER 1 approximation with factor 0.01.*
[2]*Estimation by FAO using FAO TIER 1 approximation with factor 0.015 for manure excreted for Asses, buffaloes, camels, cattle diary, cattle non-diary, chicken broilers, chicken layers, ducks, goats, horses, llamas, mules, sheep, swine breeding, swine market, and turkey.*

Table 1.
FAO estimation of biowastes in Africa sub-regions compared to globe [13].

accounting for 18% of total global CO_2 emission and significant amount of particulate [12]. Africa produces biowastes, which can be turned into useful energy, from agriculture, forest, and animal residues, as well as MSW. **Table 1** reports the FAO estimate of biowastes. Africa is located in tropical and sub-tropical region and due to good climate conditions; production rate of biomass is 4-5 times the other regions [14] leading to high agricultural and forest wastes. In 2012, 11.519 Gt was produced and 5.098 Gt was collected and in 2025, 28.155 Gt and 18.232 Gt are expected to be produced and collected every year [4]. In 2025, Africa is anticipated to generate 20.1 TWh of biomass waste and collect 12.5 TWh of garbage, compared to 8.4 TWh of biomass waste generation and 3.5 TWh of rubbish collection in 2012 [4]. This still shows low utilization of these biowastes. These wastes can be a good source of energy if they are successfully transformed. For example, in 2019 Barz et al. reported that if agricultural wastes are properly handled, they can contribute 20-40%ofprimaryenergy [14], demonstrating that all biowastes can contribute significantly. According to estimates, processing crop and agro-processing leftovers might provide 4.2 EJ in 2030, forest Residue 1.1 EJ, and animal residue 1.5 EJ. To reduce competing with food in the production of fuel, boost waste economic value, and safeguard the environment (lower GHG), biowastes should be successfully employed as an energy source [14]. The most difficult challenge is to invest in an efficient method of collecting and converting it. As a result, Africa should invest in an efficient method of collecting and converting these wastes to reduce the use of traditional energy sources. Agricultural wastes have the potential for energy production, but they compete with other uses, such as fodder, fertilizer, fiber, and construction, so an effective balance is required.

3.1 Biowastes sources

In Africa, where the main activity is agriculture and forestry with abundant cultivatable land, the biomass wastes are in abundance. The sources of wastes range from crop, forest, and animal residues, and MSW. There is a huge potential with high organic components. The MSW in Africa has high organic components of around 70% and thus making them potential for energy conversion. Unfortunately, these wastes are poorly managed and hence become environmental concern. Effective utilization can significantly offset the use of fossil fuel.

3.1.1 Municipal solid wastes

MSW has emerged worldwide as the source of energy. Report by IEA [9], electricity generated from MSW worldwide increased from 8,313 GWh in 1990 to 38,648 GWh in 2018. Africa is also generating MSW. In 2012 analysis, it was reported that Africa generated 125 million tones with 1,125 PJ but only collected 68 million tones [15]. It is projected that in 2025, 244 million tones with 2,199 PJ will be generated and 168 million tones will be collected [15]. Furthermore, it was reported that if landfill energy recovery technology is used, in 2012, 155 PJ would have been recovered while in 2025, 363 PJ will be recovered. If all wastes are collected and converted to electricity, 62.5TWh could be generated in 2012 and expectation to be 122.2 TWh. With targeted collection, 34.1 TWh and 83.8 TWh could be generated in 2012 and 2025 [4]. The increase in African population and purchasing power will lead to high generation of MSW. For example, in sub-Saharan region, MSW was predicted to increase from 300,000 t/day in 2010 to 3,250,000 t/day in 2100 [16]. This is the huge potential for use.

Apart from high potential, MSW also have high organic contents that become good source of energy. Their poor management leads to environmental pollution through degradation. The average composition of MSW in Africa, for example of sub- Saharan Africa, is about 57-78% organic, 9% paper/cardboard, 13% plastic, 4% glass, 4% metal and 13% other materials. This gives advantages on separation and treatment since large amount is energy part. Fewer amounts of plastics and metals indicate the applicability of low technologies such as anaerobic digestion can be utilized since organic parts are easily degradable. Although of high energy potential from these biodegradable organic waste, MSW remains largely an untapped resource for the continent [5]. Therefore, good policy, investment, and technology are important factor to utilize this energy.

3.1.2 Forest residue

During forest harvesting, up to 60% is left as residue which can be source of energy and soil stabilization. Furthermore, residue continues accumulating due process of forest products, such as production of saw dust. Forest residue can be used as energy source and in production of products such plywood. In 2019, Africa produced 1.02 million cubic meters (0.4% of globe) forest residue [17]. This low globe percentage is due to export of unprocessed forest products. This is the potential source of energy. The 2020 energy potential analysis in forest residue for Africa can produce energy of 10 to 5,254 PJ/yr. [18]. Low investment on technology and facilities, and poor government policy hinders their conversion. Therefore, it is important to invest in collection and conversion technologies for effective energy recovery.

3.1.3 Crop residue

In every crop harvested, the residue obtained is 25-50% (Residue to Product ratio) of the product and sometime is above 100%. These organic parts mostly are left behind to regenerate the soil, as animal feed and source of energy. In 2010, agricultural residues with an energy content of some 90 EJ were reported to have been generated worldwide and is expected to reach 128 EJ in 2050 [19]. These materials

S/No	Country	Year	Dry Wastes (kt)					Energy (PJ)	Energy consumed in 2017 [7]**
			Crops	Forest	Animal	MSW	Total		
1	Cameroon [21]	2018	45 510	2051	5153	971	53685	243	390
2	Zambia [22]	2016	12 193	6559	5	295	19051	281	438
3	Uganda [23]	2013	19 274	5549	14967	7271	47061	260	814
4	Nigeria [24]	2020	215844	4478	17165	36500	273987	1950	9525
5	Ethiopia [25, 26]	2017	53811	18400	48011	19053	72266	750	2033
6	Tanzania [27]	2018	19642	711	5946	624	26924	385	877

***The assumption made is that biowastes are used at small percentages; hence energy contributed by biomass mostly comes from fresh biomass.*

Table 2.
Example of biowaste energy potentials.

are potential for energy although compete with animal feed and soil stabilization. The analysis of 19 crops mostly grown found that crop wastes of production rate of 697.87 million tons per year can generate 10.52 EJ. This potential is enough to support 366 million population (around 33% of 2019 Sub-Saharan Africa population) that had 28.76 GJ per capital [20]. If this energy from crop residue is well utilized and assuming mean biomass energy of 20 GJ/t, the wood biomass that can be saved is around 526 million tons of wood which is equal to 122 million hectare of forest area saved. The controversy of utilizing these wastes is the removal of nutrients from the soil. Currently, uncontrolled burning of these wastes onsite leads to the nutrients loss. A good control of burning and generating energy can generate ashes that can be used as fertilizers.

Table 2 has summarized available data of biowaste from crop, forest and animal residue and MSW of six countries according to reported estimations. Furthermore the primary energy consumption for 2017 has been also recorded. Since the incorporation of biowaste analyzed is almost negligible, it can be said that the biomass contribution comes from fresh biomass. The use of biowastes can reduce this dependency.

3.2 Current management and utilization of biowastes in Africa

Biowaste resources are important for energy, animal feed, and soil stabilization. The level of utilization depends on the investment and technology. In developed countries, the collection, treatment, and conversion have been a priority for incorporation in renewable energies and protection of environment. In Africa, the utilization of biowastes is still at low level. Very small investment and conversion technologies have been implemented. In rural areas, biowastes have been little used as animal feed and sources of energy. Due to poor technology and investment, biowastes use as sources of energy has been poor. The availability of fresh biomass for animal feed, biowastes have also found little use. These wastes have been accumulating continuously. The main method of handling has been unplanned dumping and uncontrolled combustion. Crop residue burning is more regular feature and a source of greenhouse gas emissions. Crop residue burning is driven by factors like labour scarcity, short turn-around time, socio-economic constraints, ignorance of farmers towards public health issues, and low nutritive value of crop residues. Crop residue burning causes loss of valuable soil nutrients, pollution episodes, and public health issues [28]. Unplanned damping may cause pollution especially when decomposition takes place and produces methane. Improper use of biowastes such as animal wastes especially cooking and heating leads to health problems. It has

Country	Biowastes	Capacity	Reference
Mauritius	MSW-landfill	20.4 GWh	[30]
Kenya	Agricultural waste-digestion	2.8 MW	[30]
Burkina Faso	Crop waste-digestion	0.25 MW	[30]
South Africa	MSW and crop residue -digestion	4.6 MW	[30]

Table 3.
Some of biowaste to energy conversion plants.

been reported by WHO that 4.3 million deaths have occurred due to use of these wastes in cooking and heating [29]. The only advantage of poor handling of biowastes in rural area is to maintain soil quality. In rural areas, the generation of MSW is low while forest, animal, and crop wastes are high. Animal waste is commonly used as organic fertilizer and hence maintain soil ecosystem.

In urban area, the production of MSW is high while animal, forest, and crop residue is low. The big problem has been handling of MSW. Some efforts have been made in the collection and dumping of MSW. In Africa, most of collected MSW are unsorted and hence if energy conversion is decided to be done gets the challenge. In Africa, only a small amount of MSW is collected and dumped in landfill with no plan of energy recovery. There has been uncontrolled dumping and combustion which all lead to energy loss and environmental pollution.

Although there has been little effort to effectively utilize biowastes in Africa, some uses such as cooking, electricity generation, and transport fuel have been realized [30]. **Table 3** summarizes some of the plants generating electricity. Energy recovery technologies, such as landfill gas recovery and bio digesters for the organic fraction of MSW and industrial biomass are currently very limited in their implementation in Africa [31]. Gasification, direct combustion, and carbonization technologies have been in low utilization. Only noticeable biowaste waste to energy conversion has been in the use of bagasse in sugar plantation. In Tanzania, Kilombero, Mtibwa, TPC, and Kagera sugar companies have daily generation of 21,914 tons per day of bagasse and electricity installation of 40 MW [32]. The use of forest residue and sisal in Tanzania has led to the production of 21 MW. Currently, African only recycles 4% of waste produced and the African Union plans by 2023, 50% should be recycled. Other ways of managing biowaste have been producing composite manure, and animal feed.

3.3 Challenges of utilizing biowastes in Africa

The use of biowastes in energy mix has not been fully done. Lack of appropriate technologies, investment, knowledge, and policy has hindered its utilization. Poor realization of biowaste potential has led to low investment and hence utilization. The wide large of properties of biowaste due to low level of farming, production of variety of biowastes, still brings challenges in the choice of universal technology and hence need segregation stages. Furthermore, government and financial institution have little interest in funding of innovation, purchasing, and utilization of appropriate technologies [33]. Therefore, efforts are needed to increase investment, education, and introduction of appropriate conversion technology.

To increase the use of biowastes in energy mix, the following can be done. The government should have appropriate policy that promotes use of biowastes. These includes; increase of incentives, removal of fossil fuel subsides, promotion of a net zero emission, and promotion research and development of appropriate technology.

Education should be made to population on the need of using biowastes, separation of components of MSW in the disposal, discourage uncontrolled burning, introduction of simple and cheap conversion technology at household level. The peasants and farmers should be educated on the effective ways of preparation, collection, disposal, and utilization of wastes. To reduce variation obstacle, the co-generation and small processing plants should emphasized. To increase awareness, organization or companies that add value should be created.

4. Current conversion technologies of bio wastes to energy

Conversion of biowaste aims to recover energy, remove residues, and increase material value [3]. Effective conversion technologies should address financial requirements, effective recovery of energy, waste removal, and environmental protection. The development, improvement, and implementation of conversion technologies have been made due to surge in wastes that pollute environment and need for energy sustainability. The need for land has emerged as another challenge. For example, Waste to Energy (WTE) plant that can treat 30 million tons of MSW for 30 years only will use 10 hectare compared to landfill that needs 30 hectare [34].

A number of conversion technologies have been developed and applied in many parts of the world. Advanced waste to energy conversion has led the increase of energy mix from biowastes. The technologies range from direct energy conversion to more upgraded fuel. The technologies have advanced in a way that they produce energy efficiently and meet the requirements for public health while reducing air pollution and obligatory number of dumping locations [3]. These methods include direct combustion/incineration, carbonization, pyrolysis, gasification, anaerobic digestion, and oil pressing for biodiesel production. Some conversion leads to production of feedstock for chemical production. Each method has the advantages and disadvantages and thus limitation in use in African countries. The common and simple technologies in biowaste conversion have been anaerobic digestion and incineration.

4.1 Direct combustion/incineration

This is the oldest and simple, and well utilized conversion technology [34]. It deals with direct heating of fuel in presence of oxygen. It takes place at high temperature (850-1200°C) and release energy in form of heat [3]. It has been used in many biowaste plants ranging from bagasse, MSW to saw dust. Apart from energy recovery, the bottom and fly ashes can be used in other applications such as construction. The challenges of this technology are that feedstock should be of low moisture content and thus limiting many of African MSW which have high moisture content to above 40% [35]. It also may lead to pollution if poorly controlled, since it operates at high temperatures and thus releasing pollutant gases and dust. Its advantages and appropriateness in African biowastes are that it is simple, mature, and low investment cost especially if heat is the final conversion. It is also appropriate in dry biowastes such as forest residue since no pretreatment costs [3] and thus utilizing wood and crop residues produced in Africa.

4.2 Carbonization

It is the process of heating biowaste at low temperature in the absence of oxygen [36]. This process upgrades biowastes to produce usable charcoal. It is mature, cheap, and simple technology that has been used on other biomass for years and years [37, 38]. The technology works efficiently for large size and low moisture contents. Most of biowastes such as forest and crop residues have been converted into charcoal by this process. Its advantages include the cheapness, simplicity, and ability to handle variety of feedstock including lignocellulosic biomass. This method is appropriate for African biowastes although for fine materials such as sawdust and a wet material such as MSW becomes inappropriate. It is applicable in every part of Africa.

4.3 Gasification

Gasification is a mature technology and a thermochemical conversion of biomaterials in limited oxygen at high temperature (800-1600°C [39, 40]. It produces syngas that can be burnt to produce heat or used as the source of chemicals. The major constituents of syngas are carbon monoxide which poses a lot safety challenges in its handling. It requires high knowledge and thus is not appropriate for household. It is appropriate to Africa when dealing with lignocellulosic and fine biowaste although inappropriate to MSW due to high moisture content. It is appropriate to every part in Africa although due to low investment, sub-Saharan countries may not effectively fit.

4.4 Pyrolysis

Pyrolysis is the thermochemical conversion technology that operates at moderate temperature to produce solid, liquid, and gas at different composition [41, 42]. It can treat waste to produce char, oil, and gas for further energy conversion. The fast pyrolysis is favored in fine feed and operates at high temperature to produce bio oil [43]. Intermediate pyrolysis operates at moderate temperature to produce both char, oil, and gas [44]. It has an ability to handle large size, moderate moisture, and different compositions [45]. It is a technology that fits biowastes including MSW. Its appropriateness in Africa is challenged since it is sophisticated and requires high investment, and thus unfavorable in small scale. Intermediate pyrolysis has a big chance in Africa since it flexible, modular, and operates at moderate temperatures.

4.5 Anaerobic digestion

Anaerobic digestion is process that uses microorganism to breakdown organic biodegradable matter in the absence of oxygen to produce biogas [46]. It is a common technology that has been used in conversion of sugar biomass. It is simple, cheap, and works under low temperature. Its size ranges from small household to large plant. The technology is appropriate in Africa biowaste treatment since it requires small investment, mature technology, and presence of sugar biowastes especially in MSW and animal wastes. Large presence of animal residue in Africa, 25% globe, this technology is the one to be applied in all parts of Africa. Its use in lignocellulosic materials such as forest residue is inappropriate. It also has low kinetics and hence requiring larges reactors and hence investments. The residues after digestion can also be used as farm manure and thus giving it an added advantage.

4.6 Microbial fuel cell (MFC)

Microbial fuel cells use microbes as a biocatalyst and changes directly the chemical energy deposited in chemical compounds into an energy current [3]. This alternative technology reduces sludge formation, refine odor, and remove aeration supplies, all at the rate of waste reaction for electricity creation. Its advantage is the direct conversion to electricity although it has low efficiency. Due to challenges such as more sophisticated ion exchange membranes [47], this method is not appropriate in Africa especially in sub-Saharan African countries.

4.7 Landfilling

This is the technology in which biowastes are deposited and may be connected to biogas recovery and leachate processing system [3]. This method simple and cheap although may lead to environmental pollution and degradation if planning is not well done [3, 48]. This technology is appropriate in Africa since the technology is cheap, mature, and simple.

4.8 Agglomeration

This is the technology of increasing energy density by converting small particle to large particles. This increases energy density and effectiveness in conversion processes such as combustion [49]. This involves the formation of pellets and briquettes from fine biowastes that can be usable household [50]. Its challenge is the use of high energy in compressing the materials. This technology is appropriate in Africa since the technology is simple, presence of binding materials in biowaste, presence of fine materials such as charcoal dust, and cheap. All countries in Africa can utilize it due to presence of fine materials especially during charcoal production.

5. Potential of pyrolysis in biowaste conversion

Pyrolysis is the decomposition of organic materials using heat in the absence of oxygen to produce solid, liquid, and gases [51, 52]. It is said to have lower operating temperatures and emissions of air pollutants compared to combustion and gasification [52]. Pyrolysis has emerged as technology for current and future conversion technology of biomass [53]. The type, quality, and quantity of product depend on how operating parameters are controlled [52]. Its ability to treat almost all types of organic and production of solid, liquid, and gas fuel has made it a prospective technology of biomass conversion. The innovations on reactors, catalysts, and upgrading technologies have increased the importance of pyrolysis. Its level of development has made it a prospective technology for biowastes especially lignocellulosic biowastes. Therefore, pyrolysis is the current and future appropriate technology in the conversion of biowastes in Africa.

5.1 Categories of pyrolysis

Depending on the heating rate, operating temperature, and product distribution, pyrolysis can be classified as **Table 4**. It can be seen that slow pyrolysis targets char, fast and flash pyrolysis target targets bio oil while intermediate targets all. Intermediate pyrolysis has emerged as an alternative pyrolysis that is flexible, modular, economic, and ability to handle different biomass materials. It is appreciated to favor well the treatment of biowastes (**Table 4**).

The quality and distribution of products depends on a well control of parameters. Among important parameters as such as feed composition, temperature, heating rate, catalysts, feed residence time, vapor residence time, particle size, and moisture contents. The composition of feedstock should be made of organic components to lead to effective conversion. For example, cellulose and hemicelluloses produce high bio-oil while lignin can yield up to 40% of its weight as char [57]. The presence of non-organic materials reduces the amount of useful products.

Temperature also dictates the composition and yield of the products [58]. Generally, an increase in temperature increases the amount of bio-oil and gas. Higher pyrolysis temperature favors production of hydrogen, while low temperatures

Property	Slow	Intermediate	Fast	Flash
Heating rate (°C/s)	1	1-10	10-200	>1000
Feed size (mm)	5-50	1-5	<1	<0.5
Reaction temperature (°C)	400-500	400-650	850-1250	>1000
Vapor Residence time (s)	300-550	0.5-20	0.5-10	<1
Feed Water content (%)	Up to 40	Up to 40	<<10	<<10
Bio-oil Yield (%)	20-50	35-50	60-75	60-75
Bio-char Yield (%)	25-35	25-40	10-25	10-25
Gas Yield (%)	20-50	20-30	10-30	10-30

Table 4.
Classification of pyrolysis processes [54–56].

produces more char [59]. The increase in temperature reduces the amount of char but increases its quality due to decrease of the volatile matter in char.

The residence time determines the quality of the products. For example, longer residence time at low temperature favors production of biochar and its quality increases due to favoring the development of micro-and macro-pores of bio-char [60, 61]. Reduced residence time reduces the re-polymerization thus reducing the amount of char [62]. Heating rate affects the quantity, quality, and composition of products. Rapid heating gives higher volatiles and more small reactive char than those produced by a slower heating process [52]. Slower heating rate increases the amount of char due to the secondary char produced from a reaction between the primary char and the volatiles [57].

Water content affects the quality and quantity of products. It promotes the reduction of species in bio-oil and improves the production of light aromatic [63]. Water can also catalyze char formation by acting as steam activator [64, 65]. Large amount of water reduces energy content in the feed; and hence, an optimal content is required. Particle size affects the quality and quantity of products by affecting the heat transfer. The decrease in size increases heating rate and easy escape of condensable products. In addition, small size favors liquid formation, hydrogen and carbon monoxide; while large size favors the formation of char and its quality due to secondary cracking [66–68].

Inert gas carrier (sweeping gas) controls the vapor residence time. Higher flow rates cause rapid removal of products that leads to minimization of secondary reactions such as char formation, thus increasing gas production [67, 69]. Poor properties of bio-oil such as high viscosity, non-volatility, high acidity, corrosiveness, instability upon storage, lower energy density, and immiscibility with fossil fuels caused by the presence of oxygen can be improved using catalysts [70]. The catalyst increases the quality of products through increased cracking, selectivity, and de-oxygenation [71]. This increases the quality of bio-oil and biochar while decreasing their quantities [51, 72]. It has been reported that, the presence of catalyst $HZSM-5$ reduced the amount of oxygenated compounds and thus increased the quality of bio-oil [72, 73]. Studies have also found out that bio-char production increases with an increase of $NaOH$, $NaCl$, CaO, and Na_2SiO_3 [74, 75].

5.2 Pyrolysis in biowaste conversion

Pyrolysis has emerged as the appropriate technology in biowaste conversion although its applicability in household in difficult [52]. It can convert almost all materials; small and large size, lignocellulosic and non-lignocellulosic, wet and dry, and variety of compositions. It has the ability to produce usable product with little or no upgrading. For example, intermediate and fast can produce bio oil which can be used with little or no upgrading. Hydrothermal pyrolysis can convert wet materials to produce usable solid and liquids. Its high reaction rate compared to anaerobic digestion leads to small reactor. Its main challenges to be used biowaste conversion are the investment and operation cost, sensitivity of the process, and difficulty in operation. For Africa, this becomes a promising technology but difficult conversion technology for small and household users.

6. Prospect of biowaste and conversion technologies in Africa

Bioenergy utilization in African is favored by; feedstock availability, availability of proven conversion technologies, large required land for production and plant setting, and increased value chain of bioenergy [33]. Africa aims to incorporate primary sources such as biogas, biodiesel, bioethanol and other biochemicals produced from agricultural, domestic and industrial resources and with the application of simple and indigenous technologies. With increase in population which leads to high demand of energy and pollution of biowaste, the necessity for effective conversion of biowastes is important. An important issue is to have effective conversion technologies that provide required energy at minimum cost. The technologies should be simple and flexible that household can apply. The study and investment of appropriate technologies should be emphasized for sustainable energy and environment.

7. Prospect of biowaste potentials Africa

The biowastes have the opportunity to produce different types of energy resources that can replace fossil fuel. The production of liquid fuels such as bioethanol and biodiesel is important to replace/reduce importation of petrol and diesel, respectively. The following are possible products that can be produced from biowastes.

7.1 Liquid biofuel

From 2017 African energy analysis, 70.1% of 928.051 Mtoe of energy consumed was through transportation. Many of African transportation sectors depend on liquid fuel. This highlights the high demand of liquid fuel. The introduction of biofuel from biowaste can be the solution on importation of liquid fuels. Africa has little use of liquid biofuel such as biodiesel, and ethanol. Up to 2020, no electricity has been produced from liquid biofuel compared to globe 3211 MW. The potential of producing liquid biofuel from waste is high since most of wastes are sugary biomass. The use of technologies such as pyrolysis, especially fast and intermediate pyrolysis, can convert biowaste into liquid fuel. Other technologies such as gasification and anaerobic digestion can produce syngas and biogas, respectively, as feedstock for gas to liquid conversion. The fermentation process can also produce bioethanol. The production of bioethanol from biowaste can reduce the competition with food in bioethanol production. Liquid fuel can also be produced from pressing of waste shells such as coconut and cashew nut shells. Liquid biofuel has a potential of replacing fossil fuel. IRENA 2017 report of five sub-Saharan countries (Ghana, Mozambique, Nigeria, South Africa, and Uganda) [19] has predicted biomass including biowastes can produce all liquid fuel for transportation and twice for industrial electricity and heat by 2050.

7.2 Solid fuel production

African has been depending on solid fuel especially wood charcoal in household needs. Most of charcoal has been produced from forest and thus leading to deforestation. The utilization of biowastes can increase the production of charcoal while reducing deforestation. Forest and crop residues are potential feedstock for charcoal production. The agglomeration such as pelleting has the potential of increase energy quantity in the biowastes. The products can increase the efficiency of other conversion processes such as combustion.

7.3 Economic and environmental sustainability

The use of biowaste in the production of useful energy leads to creation of jobs and increased value of agriculture and forest activities [31]. This can encourage people working in these areas to increase production and hence increase in biowastes and latter economic improvement. The use of biowaste will also increase environmental protection since uncontrolled burning and dumping will be avoided.

8. Prospect of conversion technologies in Africa

There are different technologies that can help to convert biowastes to useful energy. Study done by LTS team in 2017 [76] identified possible suitable conversion

Primary conversion technology	Secondary conversion technology	End use				
		Heat	Electric Power	CHP*	Transport	cooking
Combustion	None	x				
	Steam turbine		x	x		
	Steam engine		x	x		
	Sterling engine		x	x		
	Organic Rankine cycle		x	x		
Gasification	Internal combustion Engine		x	x		
Fast pyrolysis	Combustion	x	x	x	x	
Slow pyrolysis	Combustion	x	x	x		x
Intermediate pyrolysis	Combustion	x	x	x	x	x
Oil pressing	Internal combustion engine		X	x	x	
	Transesterification				x	
Anaerobic digestion	None				x	x
	Internal combustion engine		x	x		
Fermentation	Ethanol fermentation		x	x	x	x
	Butanol fermentation				x	

**CHP means combined heat and electric power.*

Table 5.
List of appropriate biowaste to energy conversion technologies in Africa.

technologies for Africa. In applicability efficiency sequence, anaerobic digestion, gasification, direct combustion, fast pyrolysis, slow pyrolysis, and fermentation was observed [76]. Intermediate pyrolysis can be a good candidate in converting biowastes due to its advantages including; flexibility, ability to handle variety of feedstock, modular, ability to handle high moisture content, and productions of products with good quality [44]. Africa with biowastes that have variety of properties can effectively be handled using intermediate pyrolysis. **Table 5** summarizes possible effective conversion technologies of biowastes in Africa.

Biowaste is now regarded as source of energy for both energy and environment sustainability in Africa. Some polices have been formulated to increase biowaste energy in energy mix. Some funding from both government and private has been provided. Noticeable funding has come from African Development Bank Group. Example of such projects are; USD$ 1 million for Kenya for 10 MW from MSW in 2017, Bioethanol from waste for UDS$ 66 million in 2012, among others [77].

9. Conclusion

Africa is a continent that is undergoing rapid population and economic growth that require sustainable energy sources. Currently, energy production and consumption being below the global average of 2 toe per capital. The energy demand is expected to be 1600-2300 TWh by 2040 compared to 700 TWh in 2018. Increase in population from 1.2 billion in 2017 to 2.07 billion by 2040 and rapid industrialization will increase the energy demand and waste production, leading to the challenge of attaining economic and environment sustainability. Currently, energy comes from biomass at 42% and electricity is mostly from fossil fuels, leading to deforestation and pollution. The introduction of renewables in energy mix has been at low rate due to poor investment, knowledge, policy, location, and technology. Biomass is seen as the appropriate renewable energy due to abundance, affordable conversion technology, and widely distributed. To reduce deforestation and pollution, use of biowaste is appropriate solution. Although biowastes are not widely used, their use is a potential source of energy. The MSW, animal, crop, and forest residues are currently abundant in Africa and their use is a good solution for sustainable energy and environment. It is predicted that these wastes can have 20.1 TWh in 2025. Although biowastes are sources of energy, poor management, technology, and investments have hindered their use. This has led to unplanned dumping and site combustion leading to loss of energy and pollution. The introduction of appropriate technologies such as pyrolysis, gasification, and anaerobic digestion has the potential to produce solid and liquid fuels while increasing value of agriculture. Effective utilization of biowastes with other biomass will lead to energy dependency, for example by 2050; liquid biofuel can be enough for transport needs in countries such as Uganda, Nigeria, and Ghana. It is therefore important for government to formulate policy for biowastes utilization while investing on both private and public utilization plants. Education on the handling of biowastes should also be given to local population. This gives the hope that future energy and environmental sustainability in Africa can be contributed by effective utilization of biowastes.

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