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Review

Biomass resources and bioenergy potentials in Nigeria

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Energy is crucial to the wellness of humans and to a country's economic development. Unfortunately, Nigeria is challenged with low availability of electricity in rural areas and with frequent power outages and unreliability in the urban centers. Energy from biomass can potentially be an alternative approach to solving the country's electricity problem. Our estimation shows that Nigeria is capable of producing 2.01 EJ (47.97 MTOE) of energy from the 168.49 million tonnes of agricultural residues and wastes that can potentially be generated in a year. Converting the huge quantities of biomass resources to electricity will increase the energy supply, energy mix and balance of Nigeria. This paper reviewed the biomass resources available in Nigeria and the potential of generating electricity from them. It also evaluated various biomass energy conversion technologies and the application of these technologies to developing countries such as Nigeria. The benefits, challenges and research gaps in bioenergy utilization were also explored.

Key words: Biomass, bioenergy, gasification, electricity, feedstock.

INTRODUCTION

Nigeria is one of the countries in West Africa sub-region with total population of 170,123,749 in 2012 and an annual growth rate of 2.55% (CIA, 2012). Agricultural land constitutes approximately 74,500,000 ha of the total land area of 91,077,000 ha for the country. About 41.2% of the agricultural land is arable land, 11.3% forest area and 3.3% permanently cropped area. Close to 70% of Nigerian population are involved in agricultural production with more than 70% of the farming population being smallholder farmers (< 5 ha per person). About 48% of the country's population lives in the rural areas with more than 70% of the country's population living below the poverty line (CIA, 2012).

Nigeria is the sixth largest crude oil producing countries in the world. Over 95% of foreign exchange earnings and about 80% of budgetary allocation of Nigeria comes from oil (CIA, 2012), even though the oil sector contributes only 30% to Gross Domestic product (GDP) in comparison to 40% from agriculture (Oniemola and Sanusi, 2007). The GDP for Nigeria in 2011 was $238.9 billion (Table 1). Agriculture's contribution to the non-oil GDP has been consistently stable at about 40% in the recent years**.** Industrial production rate in 2011 was 2.5% with industrial sector contributing 33.6% of the GDP while services sector of the economy supply 31% of the GDP. Major foreign exchange sources are crude oil, coal, tin, columbite, rubber products, hides and skin, textiles and cements (CIA, 2012).

The estimated total energy consumption in Nigeria in 2009 was about 4.6 EJ or 111MTOE (IEA, 2012). Figure 1 shows the energy consumption in Nigeria. Traditional biomass (wood fuel and charcoal) accounted for 85% of total energy consumption which has contributed to desertification, deforestation and erosion in the country. This high percent share of biomass represents its use to meet off-grid heating and cooking, mainly in rural areas

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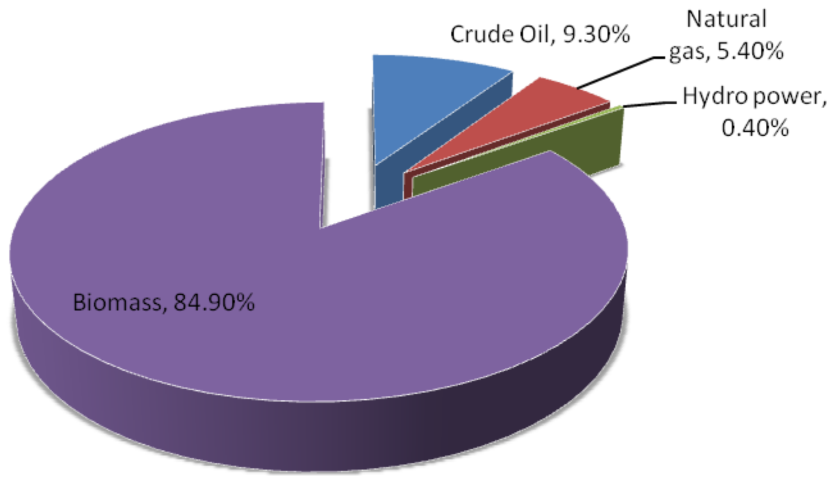

Figure 1. Energy consumption in Nigeria, 2009. Source: IEA (2012).

and by the urban poor. It has been estimated that about 80% of Nigerian households living in the rural and urban areas use wood fuel and charcoal for cooking and heating (Sambo, 2006).

A major need for industrial and commercial sectors of any country is availability of reliable electricity. Access to electricity is particularly crucial to human development as electricity is indispensable for essentials of life, the manufacturing and industrial sectors, and providing reliable public infrastructure (e.g. airports, street lights) of the country.

Electricity is therefore needed for economic growth, national development and improved standard of living (Sambo, 2006). Nigeria electricity supply system is an interconnected national grid system (Akinbami, 2001). Access to electricity is however low- about 40% on the average and as low as 18% in the rural areas (Nussbaumer et al., 2011) because of the low amount of electricity produced in Nigeria (IEA, 2012). In addition, close to 60% (that is, 80 million) Nigerians are not connected to the national electricity grid. There is also frequent power outages that can last up to 20 h daily in places connected to the grid (Akande and Olorunfemi, 2009). The low amount of electricity produced and the electricity grid problems contribute to the low per capita consumption (≈100 kWh) of electricity in Nigeria in comparison to consumption of over 10,000 kWh in developed countries (FGN, 2006). Power unreliability and unavailability have prompted industrial firms, households and commercial enterprises to depend on private diesel and petrol fueled generators (Akinbami, 2001) which have unfortunately resulted in the death of several Nigerians because of health issue such as inhaling of carbon monoxide. The persistent energy crisis in Nigeria has weakened industrialization in the country. This has significantly undermined efforts to achieve sustained economic growth, increased competitiveness of indigenous industries in domestic, regional and global markets as well as employment generation (Iwayemi, 2008) (Table 1).

According to ASABE S593.1 standard (ASABE, 2011), biomass consists of organic materials that are plant or animal based, including but not limited to dedicated energy crops, agricultural crops and trees, food and fiber crop residues, aquatic plants, forestry and wood residues, agricultural wastes, biobased segments of industrial and municipal wastes, processing by-products and other non-fossil organic materials. Three main categories of biomass are primary, secondary and tertiary biomass (ASABE, 2011). Primary biomass is produced directly by photosynthesis and harvested or collected from the field or forest where it is grown. Examples are grains, perennial grasses and wood crops, crop residues and residues from logging and forest operations. Secondary biomass consists of residues and by-product streams from food, feed, fiber, wood and materials processing plants (such as sawdust, black liquor and cheese whey), and manures from concentrated animal feeding operations. Tertiary biomass sources are post consumer residues and wastes such as fats, greases, oil, construction and demolition wood debris, other wastes wood from urban environments as well as packaging wastes, municipal solid wastes and landfill gases (ASABE, 2011).

Putting the huge quantities of biomass resources, mostly in the form of agricultural residues and wastes, which are currently disposed by burning or dumping, to energy production could potentially increase the energy supply thereby increasing energy mix and balance in Nigeria. There are also environmental benefits of reducing greenhouse gas emissions by generating electricity from biomass as well as supply of electricity in the rural areas (Pereira et al., 2012). The aim of this paper is to review the current status of biomass resources and their bioenergy potential and the possibility of utilizing biomass to generate electricity in Nigeria. The

Table 1. Selected key and compound indicators for Nigeria.

Parameter	Unit	Value	Year
Population	Million	170,123,749	2012
Population growth rate	%	2.55	2012
GDP (PPP)	Billion USD	418.7	2011
GDP	Billion USD	238.9	2011
GDP per capital (PPP)	USD	2,6000	2011
GDP growth rate	%	7.2	2011
Energy production	Mtoe	228	2009
Energy consumption	Mtoe	111	2009
Electricity Consumption	TWh	18.62	2009
CO_2 emission	Mt of CO_2	41.19	2009
Unemployment rate	%	21	2011
Industrial growth rate	%	2.5	2011
Energy production	Billion kWh	20.3	2008

Source: CIA (2012).

information gathered in this study could serve as the starting point for more detailed work on site -specific biomass assessments in Nigeria.

BIOMASS AND BIOENERGY POTENTIALS IN NIGERIA

Biomass resources in Nigeria

Biomass feedstocks can be obtained from two principal different categories: conventional agricultural products such as sugar- or starch-rich crops, and oilseeds; and lignocellulosic products and residues (Girard and Fallot, 2006). Lignocellulosic feedstocks (such as trees, shrubs, grasses, agricultural and forest residues) are potentially more abundant and cheaper than feedstock from conventional agriculture because they can be produced with fewer resources and on marginal and poor lands. Also, agricultural and forest residues are currently available from current harvesting activities without the need for additional land cultivation. The type of biomass resource available in Nigeria varies with climatic region in the country. For example the rain forest zone will generate the highest quantity of woody biomass while savannah zones will generate more crop residues (Olaoye, 2011). Major classifications on these are presented subsequently.

Agricultural resources in Nigeria

Nigerian agricultural production is characterized by large number of dispersed small scale producers employing traditional manual tools based on rain-fed crops but providing the major food needs of the country. Farming systems vary with the agro-ecological zones of the country. There are seven distinct major ecological zones as given by Gbadegesin and Akinbola (1995) in Nigeria namely:

(i) Sahel
(ii) Sudan savanna
(iii) Guinea savanna
(iv) Derived savanna
(v) Rain forest
(vi) Fresh water swamp
(vii) Mangrove swamp.

NASS (2012) surveyed twelve major crops: cowpea, cassava, maize, cocoyam, cotton, soya beans, groundnut, guinea corn, millet, rice, yam and melon. Table 2 summarizes the production data information for these major agricultural crops produced in Nigeria. The authors are aware that these crops are produced for food consumption and will not be available for energy production. However, the production data was used in our study to estimate the amount of residue available for bioenergy.

Agricultural crop residues

Agricultural residues are organic materials produced as byproduct during the harvesting and processing of agricultural crops. Agricultural residues which are produced at the time of harvest are primary or field based residues while those produced along with the product during processing are secondary or processed based residues. Agricultural residues are heterogenous, varying in bulk density, moisture content, particle size and distribution depending on the mode of handling. They are usually fibrous, low in nitrogen and vary with geographical location (Smith, 1989). Some of the field

Table 2. Production data for major agricultural crops in Nigeria, 2010.

Agricultural resource	Production area (thousand ha)	Total production (thousand metric tons)	State with highest production	Production in the state with highest (thousand metric tons)
Cowpea	2860	3368	Benue	428
Cassava	3482	42533	Benue	3792
Maize	4149	7677	Kaduna	436
Cotton	399	602	Zamfara	155
Soybeans	291	356	Benue	79
Groundnut	2785	3799	Niger	547
Sorghum	4960	7141	Kano	746
Millet	4364	5171	Sokoto	714
Rice	2433	4473	Kaduna	732

Source: NASS (2012).

Table 3. Proximate composition of major crop residues.

Crop residues	Moisture content (%)	Crude protein	Organic matter	Crude fibre	Ether extract	Ash	Nitrogen free extractives
Maize stover	10	2.8	85-91	28-46	1-2	9-15	35-53
Sorghum stover	10	3-6	96	31-35	1-2	4	50-56
Rice straw	10	2-9	75-90	20-45	1-4	10-25	29-48
Groundnut haulms	10-12	11-17	87-90	21-29	1.5-2.5	10-13	51-57
Cassava tops	70-80	17-27	89-90	8-26	3-8	6-11	35-60
Sugar cane tops	70-80	5-8	81-95	28-34	1.5-2.5	5-9	44-54
Cocoa pods	75	2-9	75-90	20-45	1-4	10-25	33-56
Empty oil palm fruit bunch	56	3-4	95	-	6-8	5	-

Source: Smith (1989).

residues are used as fertilizer, for erosion control and as fodder for livestock. Close to 50% of the residue are however burnt on cropland before the start of the next growing season. Process residues offer high promise as energy source (Cooper and Laing, 2007). Chemical composition of a crop residue varies depending on factors such as variety, age of residue or stage of harvest, physical composition including length of storage and harvesting practices (OECD/IEA, 2010). The proximate compositions of some major crop residues available in Nigeria are presented in Table 3.

Aquatic weeds

Nigeria is bounded by large Atlantic Ocean coastal regions covering eight states. The country has abundance of fast growing weeds in the coastal regions that can be harvested for energy purposes. The three common ones are described below:

1. Water hyacinth: Water hyacinth has high productivity, competitive ability and wide tolerance range (Bamgboye, 2012). Bamgboye (1994) exploited the energy potential of water hyacinth and discovered that it is suitable for biogas production.
2. Water lettuce: Water lettuce (*Pistia stratiotes* Linn) is a free growing aquatic herb with succulent leaves.
3. Brackenfern: This is also abundant in the swampy regions of Nigeria. It is a terrestrial weed which can be biodigested to produce biogas.

Bamgboye (2012) noted that more biogas can also be produced using aquatic weeds than when the substrate was terrestrial weeds. The author observed increase biogas production when water hyacinth, water lettuce and brackenfern were combined in varying proportions.

Algae

High oil prices, competing demands between foods and other biofuel sources, and the world food crisis, have ignited interest in algaculture (farming algae) for making vegetable oil, biodiesel, bioethanol, biogasoline, biomethanol, biobutanol and other biofuels, using land that is not suitable for agriculture. Among algal fuels' attractive characteristics: they can be grown with

Table 4. Forest resources in Nigeria, 2010.

Forest types	Area in forest reserves (ha)	Portion of total forested area in reserves (%)	Area in free forest areas (ha)	Total areas of forest types in FRS study area (ha)	Portion of total forested area in FRS study area (%)	Portion of total forested area in FRS study area (%)
Savanna woodland	1,424,029	52.0	6,922,662	9,736,158	58.8	58.0
Lowland rainforest	832,237	30.4	1,580,928	2,881,755	13.4	17.2
Freshwater swamp forest	226,242	8.3	1,430,436	1,656,499	12.1	9.9
Mangrove forest	48,859	1.8	945,592	997,451	8.1	5.9
Montane forest	18,271	0.7	466,036	685,150	4.0	4.1
Riparian forest	46,583	1.7	431,537	509,415	3.7	3.0
Plantain agriculture	0	0	0	0	164,100	1.0

Source: Beak Consultants (1998).

minimal impact on freshwater resources (Yang et al., 2010), can be produced using ocean and wastewater, and are biodegradable and relatively harmless to the environment if spilled (Audu and Aluyor, 2012). Harvested algae, like fossil fuel, release CO_2 when burnt but unlike fossil fuel, the CO_2 is taken out of the atmosphere by the growing algae. Algae can produce up to 300 times more oil per acre than conventional crops such as rapeseed, palms, soybeans, or Jatropha. As algae have a harvesting cycle of 1 to 10 days, their cultivation permits several harvests in a very short time-frame, a strategy differing from that associated with yearly crops (Christi, 2007). Algae can grow on land unsuitable for other established crops, for instance: arid land, land with excessively saline soil, and drought-stricken land. This minimizes the issue of taking away pieces of land from the cultivation of food crops (Schenk et al., 2008). Algae can grow 20 to 30 times faster than food crops (Duku et al., 2011).

Energy crops

Energy plantations are grown and harvested specifically for energy. Examples of energy crops that are grown in Nigeria are Jatropha, *eucalyptus* and poplar (*Populus* spp). Increased interest is currently being shown on the production of Jatropha because it is inedible to animal and therefore can be used to fence around homesteads and gardens. Jatropha, known as *Lapalapa* in Yoruba, *Wuluidu* in Igbo and *Bini da zugu* in Hausa, is a multipurpose shrub that grows wildly in Nigeria with little or no maintenance. The two varieties found in Nigeria are *Jatropha curcas* and *Jatropha glandulifera* (Unilorin, 2012). *J. curcas* is a hardy and perennial plant that grows in diverse climatic conditions and different soil-types; it can survive in arid and semi-arid or drought conditions and can therefore be grown in any part of the country; and allows for intercropping. Jatropha seeds contain around 30 to 40% oil, thus, depending on seed, yields up to 3,000 L of oil per hectare can be achieved. Raw oil can be obtained by simple cold pressing of the seeds. This oil can be used directly as fuel and better still when further processed into biodiesel (ECN, 2008). The press cake serves as a very good organic fertilizer. The distribution, establishment, management, harvesting and uses of energy crops has not been well documented in Nigeria. Only a small amount of land is currently used for energy crops production in Nigeria.

Forestry resources

Forest biomass: It is estimated that about 10 million hectares are forest reserves which is about 11.3% of the total land area of Nigeria (Beak Consultants, 1998). The classification of forests in Nigeria by Beak Consultants (1998) for FORMECU recognized eight major forest types found in 28 states of the country: savanna woodland forest, lowland rain forest, freshwater swamp forest, mangrove forest, montane forest, riparian forest, plantain (agriculture) and plantain (forest). The eight arid states in the Northern part of the country: Sokoto, Zamfara, Katsina, Jigawa, Yobe ,Borno, Gombe and Bauchi were excluded. Tables 4 and 5 show the forest resources and forest products in Nigeria, respectively.

Forest residues: Forest residues, consisting of logging residues (tops, branches) and process residues (off-cuts, sawdust) from wood industries, and demolition wood, constitute a large potential

Table 5. Production of forest products in Nigeria, 2010.

Product types	Production	
	m^3	tons
Chemical wood pulp	-	14,000
Industrial round wood	2,279,000	-
Woodfuel	63,214,728	-
Wood charcoal	-	3.940.089
Paper board	-	18,000
Particle board	40,000	-
Plywood	56,000	-
Printing /writing paper	-	1,000
Pulp wood/round/split	39,000	-
Recovered paper	-	8,000
Sawn logs + Veneer logs	7,100,000	-
Sawn wood	2,000,000	-
Veneer sheets	1,000	
Wrapping +packaging +board	-	18,000

Source: FAOSTAT (2012).

which might be available at lower prices compared to logs. The availability of these resources depends on the efficiency of the industry they come from. Typical residue yield from a tropical sawmill for export is between 15 and 20% of the total biomass (full tree), or 30 to 45% of the actual biomass (e.g., logs) delivered to sawmill. These biomass types vary in composition, volume and quality (particularly moisture content – from 12 to 55% on a dry basis), depending on the processing steps and soils of origin (Girard and Fallot, 2006).

Urban and wastes and other wastes

These are wastes generated due to the daily activities of people and can be categorized into municipal solid waste, sewage waste, food waste and fat, oil and grease.

(i) Municipal solid wastes: These are wastes generated by households and commercial concerns as a result of population concentration and activities in urban areas. The generation of municipal solid wastes increases with increasing human activities such as industrialization and urbanization (Beukering et al., 1999; Pelling and Thomas-Hope, 1999). The municipal solid wastes (MSW) in Nigeria contain all sources of unsorted wastes, such as commercial refuse, construction and demolition debris, garbage, electronic wastes, which are dumped indiscriminately on roadsides and any available open pits irrespective of the health implication on people (Onwughara et al., 2010).

(ii) Food industry wastes: Solid and liquid food wastes are generated by the food industry, hotels and restaurant. These include foods that are not up to the specified quality control standards, peelings and remains from crops, fruits and vegetables. Restaurant and hotels contributions to the GDP of the country are on the increase. With a population of 170 million, the wastes that are generated from the food industry will be considerable. Presently, most solid wastes end in the waste dumps while the waste water from food industries which contain sugars, starches and other dissolved and solid organic matter usually constitute environmental pollution. These food wastes can be anaerobically digested to produce biogas or fermented to produce ethanol.

(iii) Industrial wastewater/sewage sludge / biosolids: Large amounts of wastewater are discharged from industries and may be organic or inorganic requiring each industry to develop different methods of wastewater treatment depending on the characteristics and amount of wastewater. These methods were classified by Bhattacharya et al. (2005) as:

(a) Physical unit processes (screening, mixing, flocculation, sedimentation, floatation, filtration)
(b) Chemical unit processes (precipitation, adsorption, disinfestations)
(c) Biological unit processes (aerobic processes, anaerobic processes, anoxic denitrification).

Agro- industrial by-products mainly after processing of crops may be radically different from the starting crop. They may be rich in nitrogen (oil seed cakes, brewery and flour milling by-product) and may be either low or high in fibre (sugar cane, palm press fibre). They are less widespread geographically since they are produced at the factory sites (Smith, 1989). These can be used be anaerobically digested to produce biogas which can be used to produce electricity.

Animal wastes

Animal wastes (or manure) are mainly the droppings of livestock animals. The main constituents of this waste are organic material, moisture and ash. When decomposed under aerobic conditions, CO_2 and stabilized organic materials are produced while CH_4, CO_2 and stabilized organic material are produced in anaerobic conditions. The quantity of manure produced generally depends on the amount of feed consumed, the quality of the feed and the live weight of the animal (Duku et al., 2011). Livestock generate huge amount of manure daily which can be converted into biogas by anaerobic digestion. Animal wastes particularly ruminant offer potential for both direct and combustible fuel and as input to produce biogas.

Bioenergy potentials in Nigeria

Increasing attention is being focused globally on bioenergy as alternative to depleting fossil fuel. The suitability of a particular biomass as a potential feedstock for bioenergy production depends on various characteristics such as moisture content, calorific value, fixed carbon, oxygen, hydrogen, nitrogen, volatiles, ash content and cellulose/lignin ratio (Duku et al., 2011). The drivers for increasing the use of biomass for energy (FAO, 2008) include:

(i) Possibility of reduced carbon emissions and meeting climate change commitments,
(ii) Reduction in fossil fuel consumptions,
(iii) Rural development through employment and increased livelihood and market opportunities,
(iv) Security of supply through local production and / or processing and
(v) Technological developments because bioenergy could be used to bridge the gap between current fossil fuels technologies and future technologies

The conversion of biomass to energy will be rewarding, given the large availability of biomass resources in Nigeria.

Crop residues

Crop residues do not usually appear in official statistics hence an estimate of the amount of crop residues produced were made based on production data (such as those shown in Table 2) that were obtained from United Nations Food and Agricultural Organization (FAOSTAT, 2012) and NASS (2012).

Available data for processing residues is generally poor, due to a wide variety of processing techniques which will result in different shares of residues (Eisentraut, 2010). The ratio between main product and residue vary depending on a set of factors including variety, moisture content, nutrient supply and use of chemical growth regulators among others. In reality, not all existing residues can be used for bioenergy production due to scattered abundance, technical constraints, ecosystem functions and other uses (animal fodders, fertilizer, domestic heating and cooking). The 2010 production data of some crops were combined with the residue- to- product ratios (RPR) of the different crops to obtain the amount of residues for each annual crop (Table 6) and from perennial plantation crops (Table 7). Our analysis showed that the estimated total amount of crop residue that is potentially available for energy is 150 million tonnes. Using 30% conversion that is typically obtained in biomass to energy conversion systems efficiency and the heating value data, these residues can provide 0.60 EJ (or 34% of the current energy consumed in Nigeria).

Forest residues

Table 8 present the forest and wood processing residues estimated for Nigeria using 2010 production data.

(i) Logging residues: The average recovery factor of 60% as given by Koopmans and Koppejan (1997) was used to generate the amount of logging residues in Nigeria. This generated residues from solid wood (stumps, branches, leaves, defect logs, off-cuts) and saw dust of 1,367,400 m^3 (9.54 MJ).
(ii) Sawmilling: A yield factor of 38% solid wood waste (bark, slabs, edgings and trimming) and 12% sawdust as given by Koopmans and Koppejan (1997) were used to generate an estimate of 1,139,500 m^3 (7.97 MJ) as potential residues for Nigeria in 2010 which can be used for bioenergy.
(iii) Plywood production: Plywood production involves cutting of logs to the required length and debarking logs. A recovery factor of 45% solid wood residues consisting of log ends and trims, bark, log cores, green veneer waste, dry veneer waste, trimmings and rejected plywood and sanding plywood dust of 5% as given by Koopmans and Koppejan (1997) were used to generate 28,000 m^3 (0.195 MJ) residues for Nigeria in 2010 which can be used for bioenergy.
(iv) Particle board production: All types of wood can be used for production of particle board. An estimation of 4000 m^3 (27.90 KJ) was generated for Nigeria based on residues factor of 10% as given by Koopmans and Koppejan (1997) which can be used for bioenergy.

Municipal solid wastes

Figure 2 shows the topology of municipal solid wastes (MSW) in Ibadan, Nigeria. Bamgboye and Ojolo (2004)

Table 6. Residues estimate from agricultural crops, 2010.

Crop	Production (000 ton)	Component	RPR*	Moisture Content*, %	Total amount of residue Million tons	% Available	Weight available Million tons	LHV* (MJ/Kg)	Total energy available (PJ)	Source (s)*
Rice	3368.24	Straw	1.757	12.71	7.86	100	7.86	16.02	125.92	Koopmans and Koppeyan (1997)
		Husk	0.2	2.37	1.19	100	1.19	19.33	23.00	Bhattacharya et al. (1993)
Maize	7676.85	Stalk	2.0	15	15.35	70	10.75	19.66	211.35	Vimal and Tyagi 1984; Koopmans and Koppeyan (1997)
		Cob	0.273	7.53	2.10	100	2.10	16.28	34.19	Bhattacharya et al. (1993)
		Husk	0.2	11.11	1.54	60	0.92	15.56	14.32	Vimal (1979); Jekayinfa and Scholz (2007)
Cassava	42533.17	Stalks	2.0	15	85.07	20	17.01	17.50	297.68	AIT-EEC (1983)
		Peelings	3	50	127.60	60	76.56	10.61	812.30	Koopmans and Koppeyan (1997); Jekayinfa and Scholz (2007)
Groundnut	3799.25	Shells	0.477	8.2	1.81	100	1.81	15.66	28.35	Bhattacharya et al. (1993)
		Straw	2.3	15	8.74	50	4.37	17.58	76.83	Vimal and Tyagi 1984; Ryan and Openshaw (1991)
Soybean	365.06	Straw	2.5	15	0.91	100	0.91	12.38	11.27	Bhattacharya et al. (1993)
		Pods	1.0	15	0.37	100	0.37	12.38	4.58	Bhattacharya et al. (1993)
Sugar cane	481.51	Baggasse	0.29	50	0.14	80	0.11	18.10	1.99	Bhattacharya et al. (1993)
		Tops/Leaves	0.30	10	0.14	100	0.14	15.81	2.21	USAID (1989)
Cotton	602.44	Stalk	3.743	12	2.25	100	2.25	18.61	41.87	Bhattacharya et al. (1993)
Millet	5170.45	Straw	1.75	15	9.05	80	7.24	12.38	89.63	Bhattacharya et al. (1993)
Sorghum	7140.96	Straw	1.25	15	8.93	80	7.14	12.38	88.39	Bhattacharya et al. (1993)
Cowpea	3368.24	Shell	2.90		9.77	50	4.89	19.44	95.06	Ryan and Openshaw (1991); Jekayinfa and Scholz (2007)
Total							145.62		1,958.94	

Table 7. Residues from Perennial Plantation Crops, 2010.

Crop type	Area (ha)	Production (kg)	Residue	Total amount Million tons	Fraction available	Total amount available million tons	LVH* (MJ/kg)	Total energy potential (PJ)	Sources*
Oil Palm	3,200,000	8,500,000	Fibre	1.275	0.80	1.020	11.34	11.57	Lim (1986); Ma and Ong (1986)
			Empty bunches	1.955	1.0	1.955	8.16	15.95	Lim (1986); Ma and Ong (1986)
		1,170,000	Palm kernel	1.170	0.75	0.878	18.83	16.53	Lim (1986); Ma and Ong (1986)
Cocoa	1,344,500	360,000,000	Pods	0.202	0.90	0.181	15.12	2.74	Lim (1986); Quaak et al. (1999)
Coconut	36,200	170,000	Husk	0.0803	0.90	0.072	18.63	1.34	PCA (1979); Bhattacharya et al. (1993)
			Shell	0.0376	0.75	0.028	18.09	0.51	PCA (1979); Bhattacharya et al. (1993)
Natural rubber	345,000	143,500,000	Leaves	0.483	0.70	0.338	17.63	5.96	Koopmans and Koppejan (1997); Quaak et al. (1999)
Total						4.472		54.6	

Table 8. Forest and wood processing residues in Nigeria, 2010.

Types	Residues	Percent of residues*	Total residues (m^3)
Logging	Solid wood	40	911,600
	Dust	20	455,800
Sawmilling	Sawdust	12	273,480
	Solid wood	38	866,020
Plywood	Solid	45	25,200
	Dust	5	2,800
Particle board	Dust	10	4,000
Wood fuel			65,753,628
Total			

Source: FAOSTAT (2012) *Koopmans and Koppejan (1997).

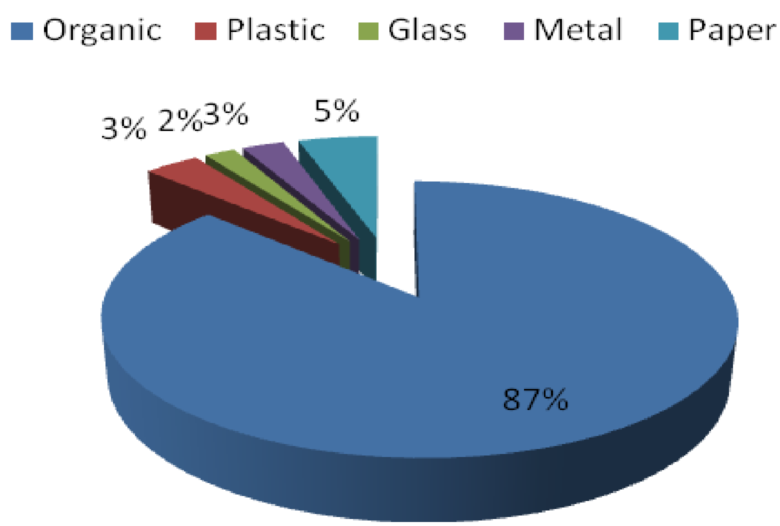

Figure 2. Municipal solid waste composition in Nigeria. Source : Eisa and Visvanathan (2002).

studied MSW in Lagos Island, their result showed average percentage by weight of the MSW constituents were 60.55 for vegetable materials, 15.38 for paper products, 6.26 for plastics/rubber, 3.78 for ferrous metals, 3.48 for textiles, 2.19 for glass and 0.36 for non ferrous metals. The vegetable products yield 5.15 dm^3/kg TS to 5.83 dm^3/kg TS (Ojolo and Bamgboye, 2005).

Eisa and Visvanathan (2002) gave a MSW generation rate of 1.10 kg/capita/day for Ibadan. If this is used for the estimate, 3.168 million tonnes of waste was generated by the urban population in Nigeria in 2010. If 60% recovery was possible, 1.90 million tonnes (with equivalent energy of 186.33 GJ) of waste can potentially be converted into energy.

Animal waste

Using the livestock figures of 2010 as shown in Table 9, the average dry matter production per animal per day and the biogas yield per kg of dry matter, the estimate of total dry dung production and the theoretical potential biogas yield per annum for Nigeria is presented in Table 9. A total estimate of 15.762 million tons per year of dry matter from animal dung was calculated for 2010 with potential biogas yield of 4.19×10^9 m^3/year (29.25 GJ).

Human waste

With a total population of 158,423,000 in 2010, Nigeria has a great amount of potential biomass resource in human waste. If the estimate is based on the urban population and on a dry matter of 0.09 kg per head per day as given by Jossy (1994), the total dry matter produced per year in Nigeria was 2.59 million tons in 2010 (Table 10). With a biogas yield of 0.45 m^3 per kg dry

Table 9. Animal wastes production and potential for biogas yield in Nigeria, 2010.

Type	Population	Dry matter production kg/head/day*	Amount of dry matter produced per year kg	Biogas yield			
				Fraction recoverable	Amount of dry matter available per year kg	m^3 /kg dry matter**	Total potential m^3/year
Cattle	18,871,339	2.860	1.970×10^{10}	0.3	5.910×10^9	0.20	1.182×10^9
Goat	65,651,252	0.552	1.323×10^{10}	0.4	5.292×10^9	0.25	1.323×10^9
Pig	6,040,820	0.661	1.457×10^9	1.0	1.457×10^9	0.56	0.815×10^9
Sheep	37,422,554	0.329	4.493×10^9	0.3	1.348×10^9	0.25	0.337×10^9
Chicken	101,676,710	0.043	1.596×10^9	1.0	1.596×10^9	0.28	0.447×10^9
Duck	9,553,911	0.051	0.177×10^9	0.9	0.159×10^9	0.56	0.089×10^9
Total					15.76×10^9		4.19×10^9

Source: NASS (2012) * Elauria et al., (1999) ** Jain (1993).

Table 10. Biogas yield from urban population in Nigeria, 2010.

Item	Value	Reference
Population		
Urban	78,900,000	CIA (2012)
Rural	79,524,000	CIA (2012)
Dry matter production, kg/head/day	0.090	Jossy (1994)
Total dry matter per year, million tons	2.592	
Biogas yield, m^3 per kg dry matter	0.45	Jain (1993)
Total biogas potential, m^3/year	1.17×10^9	

matter as given by Jain (1993), the total estimated biogas potential for the country was 1.17×10^9 m^3/year (8.13 GJ) which can be used for bioenergy.

BIOMASS CONVERSION TECHNOLOGIES IN NIGERIA

While several technologies for generating bioenergy heat and power already exist, there is a need to extend the use of most efficient technologies available today and to complete the development and deployment of a number of new technology options. Biomass can be converted to energy, fuels and products through two main conversion pathways- thermochemical and biochemical conversion pathways (Table 11). The appropriate conversion technology for a biomass is influenced by factors such as type and quantity of biomass feedstock, the desired form of energy (end –use requirements, environmental standards, economic considerations and project specific factors) (Mckendry, 2002). Also, the biomass conversion efficiency depend on the use, material, size and shape of the particles, gas flow and types of reactors (Pereira et al., 2012). The biomass conversion technology should be tailored to the biomass type to achieve optimum outcomes (Barber and Warnken, 2008). A detailed discussion of each conversion pathway is given below. A number of modern biomass energy technologies (BETs) are currently at different stages of research, development, demonstration and commercialization. The global installed capacity of electricity generation from biomass as at 2000 was about 40,000 MW (Turkenburg, 2000).

Biochemical

Biochemical conversion involves breaking down the hemicellulose fraction and making the remaining cellulose material more accessible for reaction. The lignin components of the original biomass remain unreacted throughout the biochemical process. The lignin can be recovered and used as fuel by thermochemical conversion process. The two biochemical process options are - anaerobic digestion and fermentation (McKendary, 2002). In anaerobic digestion, high moisture content (85 to 90%) biomass is converted into biogas by microorganisms in the absence of oxygen to produce a mixture of carbon dioxide and methane with small quantities of other gases such as hydrogen sulfide

Table 11. Primary processing technologies and the ability to process different biomolecules.

Conversion technology	Fats and Oils	Biomass resource		
		Protein	Sugars and Starch	Lignocellulosics
Direct combustion	√			√
Anaerobic digestion	√	√	√	Cellulose only
Fermentation		√	√	Cellulose only
Vegetable oil transeterification	√			
Pyrolysis	√	√	√	√
Gasification	√	√	√	√

Source: Barber and Warnken (2008).

(European Commission, 1999). Raw biogas has to be cleaned and upgraded before it can be used in engines or heaters. This is because of the impurities (hydrogen sulfide, dust, water halogenate hydrocarbons) that are present in the raw biogas that cause corrosion problems in processing, handling and storage facilities and equipment. The biogas produced has an energy content that is about 20 to 40% of the lower heating value of the feedstock (McKendry, 2002).

Conversion of starch feedstocks such as maize, cassava, yam, sweet potato and rice into bioethanol have been successfully commercialized in several countries. For examples, virtually all of the 13.9 billion gallons of ethanol produced (which is 57.5% of global bioethanol production) in USA in 2011 was from maize (EIA, 2012). Nigeria has the climate conditions to produce maize and other starchy feedstocks. Brazil also developed a successful bioethanol program based on fermentation of sugar in sugarcane feedstock to ethanol. In 2011, Brazil produced 5.57 billion gallons of ethanol fuel- representing 24.9 % of the world‘s total use of ethanol as fuel. Also, ethanol is about 50 % of the fuel used in gasoline based market in Brazil (RFA, 2011). Nigeria has similar climate to Brazil and can produce sugar cane. It is therefore possible for Nigeria to supply a major part of the fuel for gasoline- based cars and generators for electricity with ethanol from sugar cane and other high sugar producing crops such as sugar beet, sweet sorghum and various fruits.

Bioethanol production from lignocelulosic biomass consists of three major steps: pretreatment, enzymatic hydrolysis and fermentation (Lim et al., 2012). The purpose of the pretreatment is to increase biomass surface area, decrease crystallinity of cellulose, eliminate hemicellulose and break the lignin seal. Chemicals such as dilute acid, sulfur dioxide, ammonia expansion, aqueous ammonia and lime are used for pretreating lignocellulosic feedstocks (Sun and Cheng, 2002). Enzymatic hydrolysis involves conversion of cellulose into glucose and hemicellulose into several pentoses and hexoses (Taherzadeh and Niklasson, 2004). The glucose is then fermented into ethanol by selected microorganisms. Even though the conversion of lignocellulosics has been proven in research and pilot laboratories around the world, there are technological, logistics and economic obstacles that have prevented the full scale installation and operation of commercial production plants.

Thermochemical conversion

This involves any of the following process options; combustion, pyrolysis, gasification and conversion to other energy products (Lim et al., 2012, Goyal et al., 2008). Combustion used mostly for biomass with moisture content less than 50% unless it is pre-dried, converts the chemical energy stored in biomass into heat, mechanical power or electricity in stoves, furnaces, boilers, steam turbines or turbo – generators. The combustion technologies can either by fixed bed or fluidized bed systems. Biomass can be co-fired in existing coal power plants or combusted in a dedicated combined heat and power (CHP) plants. When biomass is co-fired at less than 10% of coal, only minor changes in handling equipment and boiler is needed. Higher quantity of biomass will require separate burners and dryers for the biomass. Use of low-cost biomass has a short payback period of 2 years or less. However, low quality biomass such as herbaceous crops may produce tar and cause slagging and fouling that may affect plant reliability and increase costs. Dedicated CHP plants are limited to $1/10^{th}$ the size of typical coal power plants (~500 MW) because of cost of transporting and availability of feedstock (IEA, 2007). The small size roughly doubles the investment cost per kW and results in lower electrical efficiency (less than 30%) compared to coal power plants (IEA, 2007). Co-firing seems to be a viable option in existing coal power plants in Nigeria.

Gasification

This is the conversion of biomass into combustible gas mixture by the partial oxidation of biomass at temperatures of about 800 to 900°C under a controlled amount of air. The gas (often called synthesis or syngas)

Table 12. Targets for renewable energy generation (MW) in Nigeria.

Resource	Short 2008	Medium 2015	Long 2030
Hydro(large)	1930	5930	48,000
Hydro (small)	100	734	19,000
Solar PV	5	120	500
Solar Thermal	-	1	5
Biomass	-	100	800
Wind	1	20	40
All renewable	2,036	6,905	68,345
All energy resources	15,000	30,000	190,000
	14%	23%	36%

Source: ECN (2006).

produced consists of a mixture of carbon monoxide (CO) (18 to 20%), hydrogen (H_2) (18 to 20%), carbon dioxide (CO_2) (8 to 10%), methane (CH_4)(2 to 3%), small quantitiesof other light hydrocarbons(C_5H_{10}), and steam (H_2O) including nitrogen (N_2) present in the air that was supplied for the reaction (Pereira et al., 2012). The low calorific value gas produced (about 4 to 6 MJ/Nm^2) can be burnt directly or used as a fuel for gas engines and gas turbines for electricity and can be used as a feedstock in the production of chemicals (McKendry, 2002). The composition of the syngas is influenced by gasification conditions such as temperature, equivalent ratio and pressure (El-Emam et al., 2012).

Pyrolysis

This involves thermal decomposition of biomass under pressure, in the absence of oxygen and at temperatures of 350 to 550°C to produce three fractions - liquid fraction (often called bio-oil), solid (mostly ash) and gaseous fractions. The bio-oil can be used in engines, turbines and feedstock refineries (Lim et al., 2012). Two studies on bio-oil production were carried out in Nigeria. Bamgboye and Oniya (2003) found that corn cobs produced in Nigeria can be converted into bio-oil. Ogunsina et al. (2009) also used thermo- chemical conversion of cashew nut shells into fuel products. The heating value of the shells was 16.69 MJ/kg while the tar oil produced had heating value 13.17 MJ/kg.

Vegetable oil transesterification

This involves the extraction of triglycerides (such as vegetable oil) from biomass and conversion of the triglyceride into alkyl esters (commonly known as biodiesel) by reacting the triglycerides with alcohol, using sodium hydroxide or some other strong alkali as catalyst. Glycerin is a byproduct of the process (ASABE, 2011). Apart from vegetable oils, biodiesel can be manufactured from animal fats and recycled restaurant greases. Biodiesel can be used in pure form (B100) or may be blended with petroleum diesel at any concentration (for example B20 means 20% biodiesel and 80% petroleum diesel). Blends of 20% biodiesel and lower (that is, B 20 and lower) can be used in diesel equipment. Most diesel car and engine manufacturers warranty use of B5. When used in its pure form (that is, B100), engine modification may be required to minimize maintenance and performance problems. Use of biodiesel in conventional diesel engines has been shown to substantially reduce emissions of unburned hydrocarbons, carbon monoxide, sulfates and other particulate compounds. Biodiesel reduced fuel system wear by offering better lubricating properties and increases the life of fuel injection systems (Ma and Hanna, 1999). There are opportunities for production of biodiesel in Nigeria because of the availability of oil bearing materials such as palm trees, groundnut, and coconut. There is presently no documented information on the amount of biodiesel produced in Nigeria.

NIGERIAN GOVERNMENT EFFORTS IN BIOENERGY DEVELOPMENT

National policies and targets

The Federal Government of Nigeria sets out its vision, policies and objectives for promoting electricity derived from renewable energy sources in the Policy Guidelines in Renewable Electricity. A study conducted by the Presidential Committee on a 25 year Power development plan developed a projected electricity demand profile for the nation of about 15,000 MW, 30,000 MW and 190,000MW in the short, medium and long terms on the basis of a 10% economic growth rate scenario (Sambo, 2006). A study by the Energy Commission of Nigeria indicated that renewable electricity is expected to contribute about 14, 23 and 36% of the total electricity demand in the short, medium and long terms respectively as dictated by the National Energy Policy (ECN, 2003) (Table 12).

Anticipated benefits of bioenergy industry in Nigeria

There are enormous benefits rural area stand to gain if bioenergy industry is properly developed in Nigeria as given by Agba et al. (2010). These benefits include:

(i) Employment and wealth creation: Bioenergy will lead to modernization of rural agriculture including loans and agriculture incentives from government and the private sector. New jobs for highly skilled labour would be created in bioenergy industries and where dedicated energy crops would be cultivated. This in turn will increase the number of manufacturing facilities and jobs in the rural sector of the country. With an estimated 60% of the countries workforce employed in the agriculture sector, the attendant proportion would expand to about 70 to 80% when bioenergy industry is fully developed in the country. This would improve the earnings of rural dwellers thereby creating wealth.
(ii) Rural infrastructure development: Most rural areas in Nigeria lack basic amenities. The involvement in biomass resource cultivation, harvesting and processing could ginger up rural development by improving rural livelihood and creating new income opportunities. Bioenergy industry would attract and increase investments which would lead to the development of rural infrastructures such as portable water, roads, railways, electricity, hospitals and markets.
(iii) Rural market expansion: Bioenergy industry would attract other services providers that would create multiplier effects. Commercial activities would expand with increase in the demand for goods from farmers. Those dwelling in the rural areas would also have access to varieties of goods and services.
(iv) Poverty reduction: Development of bioenergy industry would reduce rural poverty depicted by low income, unemployment and lack of basic amenities/infrastructures.
(v) Skill acquisition and increase in school enrollment: The bioenergy industry and other services providers would require skilled and semi-skilled labour which would lead to the establishment of skill acquisition centres in rural areas. Scholarship would be provided to rural dwellers (host communities) as part of their corporate social responsibilities.

LIMITATIONS OF BIOENERGY INDUSTRY IN NIGERIA

Challenges of bioenergy industry in Nigeria

(i) Land ownership structure: Bioenergy industry would require large cultivation of energy crops. The current communally ownership of land, with a pocket of private ownerships would pose as hindrance to large scale farming which can affect the availability of raw material for the bioenergy production.
(ii) Lack of Infrastructure: Lack of basic amenities in rural communities would impede the effective development of bioenergy industry.
(iii) Fear of food shortage: There are likely fears that biofuel industry would threaten food security in rural areas.
(iv) Environmental problems: Some communities who are already suffering from pollutions due to the activities of agri- based industries may be exercising fear that bioenergy industry would do the same which may impede its development.
(v) Lack of skilled labour: There would be need for specialized skilled workers in the new bioenergy industry as workers with requisite knowledge which may not be readily available for smooth running.
(vi) Inadequate funds: Cultivation of energy crops requires long term loans and incentives. Presently, the poverty situation in rural areas impedes farmers from getting loans and government incentives are also inadequate thus affecting productivity.

Research gaps for bioenergy industries in Nigeria

Some research gaps for the bioenergy industries in Nigeria as given by Sambo (2006) are enumerated below:

(i) Capacity limitation: Technical expertise to develop, deploy and manage renewable energy is inadequate and worst still, is not relied upon in the country as expertise is often sourced from outside the Nigeria. Also the infrastructure for the manufacture of renewable electricity system components is not available in the country.
(ii) Financial and fiscal incentives: Financial and fiscal incentives are not available to fast track the development of the supply and demand sides of the renewable energy electricity market. There is also a general lack of awareness of the benefits of renewable energy electricity in the country. No agency is presently charged with the responsibility to license smaller capacities which are often associated with the renewable energy electricity.
(iii) Intermittency of resource availability: All renewable resources for electricity generation are available intermittently and cyclic. There is also inadequate resource assessment and reliable resource database to assist investment decisions for renewable energy electricity industry. The challenge of energy storage and system management during periods of lack of resources adds to the complexity of the system.

CONCLUSIONS

There exist a great opportunities for exploitation of different types of biomass in Nigeria with an estimated 2.01 EJ (47.97 MTOE) biomass residues and wastes available to be exploited annually. The conversion of biomass to energy will be rewarding, given the large availability of the biomass resources in the country. Utilization of bioenergy has not been given serious implementation attention in Nigeria as if the fossil fuel will be continuing forever. It is important for Nigeria to look inward to see that the future generations will not be put at disadvantage through the continued exploitation of fossil resources by exploring alternatives energy sources. The energy challenge of Nigeria will be a thing of the past if the abundant biomass resources in the country is tapped and used to generate electricity. Although, there has been an upscale of activities by government towards increasing the energy mix within the country for electricity production through renewable sources. It is hoped however, that the laudable programmes and policies on bioenergy will be given some bites.

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REFERENCES

Agba A, Ogaboh M, Ushie ME, Abam FI, Agba MS, Okoro J (2010). Developing the Biofuel industry for effective rural transformation in Nigeria. Eur. J. Sci. Res. 40(4):441-449.

AIT-EEC (1983). Evaluation and selection of lingo-cellulose wastes which can be converted into substitute fuels. Project report submitted to EEC, Belgium.

Akande SO, Olorunfemi FB (2009). Research and development potentials in Biofuels production in Nigeria. African Res. Rev. 3(3):34-45.

Akinbami JK (2001). Renewable energy resources and technologies in Nigeria: Present situation, future prospects and policy framework. Mitigation and adaption strategies for global change 6:151-181.

ASABE (2011). Terminology and definition for biomass production, harvesting and collection, storage, processing, conversion and utilization. ANSI/ASABE S593.1. January 2011. pp 821-824.

Audu TOK, Aluyor EO (2012). Potential of Bioenergy and Biofuels technology development in Nigeria. Petr. Techn. Dev. J. 1-7.

Bamgboye AI (1994). Pretreatment measures to accelerate and maximizing water hyacinth (*Erchhornia crassipes*) biodigestibilty for biogas production. Unpublished PhD Thesis: University of Ibadan.

Bamgboye AI , Ojolo SJ (2004). Characterization of municipal solid wastes being generated in Lagos State , Nigeria. LAUTECH J. Eng. Tech. 2(1):36-38.

Bamgboye IA (2012). The potential of producing fuel from biomass in Nigeria. In Jekayinfa SO (Ed). Building a non-oil export based economy for Nigeria: the potential of value -added products from agricultural residues. Cuvillier Verlag Gottingen. pp. 35-41.

Bamgboye AI, Oniya O (2003). Pyrolytic conversion of corn cobs to medium grade fuels and chemical preservatives. FUTAJEET 3(2):50-53.

Barber M, Warnken M (2008). Biomass technology review: Processing for energy and materials. Crucible carbon for sustainability . Victoria. www.sustainability.vic.gov.au /resources/documents /biomass_Technology_Review.pdf. P. 44.

Beak Consultants (1998). Forest resources study. National report (draft) Vol 1. FORMECU. Federal Department of Forestry. Abuja. Nigeria.

Beukering P, Sehker M, Gerlagh R, Kumar V (1999). Analyzing urban solid waste in developing countries: a perspective on Banglore, India. Warmer Bull. 67: 8-10.

Bhattacharya SC, Pham HL, Shrestha RM ,Vu QV (1993). CO_2 emissions due to fossil and traditional fuels, residues and wastes in Asia. AIT workshop on Global warming issues in Asia. 8-10 September 1992, AIT. Bangkok. Thailand.

Bhattacharya SC, Abdulsalam P, Runqing H, Somashekar HI, Racelis DA, Rathnasiri PG , Yingyuad R (2005). An assessment of the potential for non –plantation biomass resources in selected Asian countries for 2010. Biomass Bioenergy. 29:153-166.

Christi Y (2007). Biodiesel from microalgae. Biotechnol. Adv. 25:294-306.

CIA (2012). The World factbook: Nigeria. http://www.cia.gov/library/publications/the world -factbook/index.html. Accessed 24th August 2012.

Cooper CJ Laing CA (2007). A macro analysis of crop residue and animal wastes as a potential energy source in Africa. J. Energy Southern Africa 18(1):10-19.

Duku MH, Gu S, Hagan ES (2011). A comprehensive review of biomass resources and biofuels potential in Ghana. Renewable Sustainable Energy Rev. 15:404-415.

Eisa M, Visvanathan C (2002). Municipal solid waste management in Asia and Africa. A comparative analysis. Cleaner production and Environmental Management Branch, United Nations Industrial Development Organization. Vienna, Austria, 69 p.

Eisentraut A (2010). Sustainable production of second- generation biofuels: potential and perspectives in major economies and developing countries. OECD/IEA 9 rue de la Federation. 75739 Paris cedex 15. France .222p. www.iea.org. Accessed 28th August 2012.

El-Emam RS, Dincer I, Naterer GF (2012). Energy and exergy analyses of an integrated SOFC and coal gasification system. Int. J. Hydr. Energy 37:1689-97.

Energy Commission of Nigeria (ECN) (2003). National Energy Policy.www.energy.gov.ng. Accessed on 12th August 2012.

Energy Commission of Nigeria (ECN) (2006). Renewable Energy Master Plan (Draft). www.energy.gov.ng. Accessed on 12th August 2012.

Energy Commission of Nigeria (ECN) (2008). Communiqué of National workshop on sustainable Jatropha for energy development. 6th -7th May, Mambayya house, Kano. www.energy.gov.ng. Accessed on 3rd January 2013.

Energy Information Administration (EIA) (2012) Biofuels issues and trends. USDA Washington, DC 20585. www.eia.gov/biofuels/issuestrends/pdf/bit/pdf. Accessed 06/1/13.

European Commission (1999). Biomass conversion technologies- Achievements and prospects for heat and power generation. Luxembourg: Office for official publications of European Communities. EUR 18029. P. 178.

FAO (2008). The state of food and agriculture. Biofuels: Prospects, risks and opportunities. Food and Agriculture Organization of the United Nations Publication. Rome. P. 128.

FAOSTAT (2012) FAO statistics division. http://www. faostats.fao.org. Accessed 31/08/2012.

Federal Government of Nigeria (2006). Renewable Electricity Policy Guidelines. Federal Ministry of Power and Steel. P. 37.

Gbadegesin A, Akinbola GE (1995). Nigeria: Reference soil of the southern guinea savanna of south western Nigeria. Soil Brief Nigeria 7. University of Ibadan, Ibadan and International Soil Reference and Information Centre. Wageningen. P. 13.

Girard P, Fallot A (2006). Review of existing and emerging technologies for the production of biofuels in developing countries. Energy for Sustainable Development. 10(2):92-108.

Goyal HB, Seal D, Saxena RC (2008). Biofuels from thermochemical conversion of renewable resources: A review. Renewable Sustainable Energy Rev. 12:504-517.

IEA (2007). Biomass for power generation and CHP. IEA Energy Technology Essentials. Report ETE 03.

IEA (2012). Energy balance for Nigeria . OECD/IEA . http:// data.iea.org. Accessed 1st September 2012.

Iwayemi A (2008). Nigeria's dual energy problems: Policy issues and

challenges. Int. Assoc. Energy Econ. 53:17-21.
Jain MC (1993). Bioconversion of organic wastes for fuel and manure. Fertilizer News 38 (4):55-61.
Jekayinfa SO, Scholz V (2007). Assessment of availability and cost of energetically usable crop residues in Nigeria. Paper Presented at Conference on International Agricultural Research for Development . Tropentag 2007. University of Kassel- Witzenhausen and University of Gottingen, October 9-11 2007.
Jossy MT (1994). A study of greenhouse gases emission from agricultural residues in Asia. M. Eng Thesis No ET-94-15, Asian Institute of Technology, Bangkok, Thailand.
Koopmans A, Koppeyan J (1997). Agricultural and forest residues - generation, utilization and availability. Regional consultation on modern applications of biomass energy. 6-10 January. Kuala Lumpur, Malaysia.
Lim JS, Manan ZA, Wan Alwi SR, Hashim H (2012). A review on utilization of biomass from rice industry as a source of renewable energy. Renewable and Sustainable Energy Reviews 16: 3084-3094.
Lim KO (1986). The energy potential and current utilization of agriculture and logging wastes in Malaysia. Renewable Energy Review J. 8(2):57-75.
Ma AN, Ong ASH(1986). Biomass energy from the palm oil industry. In: Proceedings of the ASEAN conference on energy from biomass. Bangkok, Thailand. p 13-21.
Ma F, Hanna MA (1999). Biodiesel Production: a review. Bioresource Technology 70: 1-15.
McKendry P (2002). Energy production from biomass (part 2): Conversion technologies. Bioresource Technology 83: 47-54.
NASS (2012). Collaborative survey on National agricultural sample survey 2010/2011. National Bureau of Statistics and Federal Ministry of Agriculture and Rural Development.
Nussbaumer P, Bazilian M, Modi V, Yumkella KK (2011). Measuring energy poverty: Focusing on what matters. Oxford Poverty and Human Development Initiative (OPHI) Working paper No 42: 27 p.
OECD/IEA (2010). Sustainable production of second – generation biofuels, potential and perspectives in major economies and developing countries, Information paper. http://www.iea.org/papers/2010/second_generation_biofuels.pdf. Accessed 5th August 2012.
Ogunsina BS , Ojolo SJ, Bamgboye AI, Muritala AO, Femi- Falade O, Imoudu DE, Fashogbon SK(2009). Thermochemical conversion of cashew nut shells into alternative energy sources. Proceedings of 3rd International Conference of WASAE and 9th International Conference of Nigerian Institution of Agricultural Engineers . OAU Ile Ife. Nigeria.
Ojolo SJ , Bamgboye AI (2005). Biogas production from municipal solid waste. Proceedings of International Conference of Engineering, Lagos /. Nigeria. pp. 303-310.
Olaoye JO (2011). An analysis of the environmental impacts of energy crops in Nigeria towards environmental sustainability. In: Ogunlela, AO (Ed) . Tillage for Agricultural Productivity and Environmental Sustainability. Proceedings of Nigerian Branch of International Soil Tillage Research Organization. pp. 204-212.
Oniemola PK, Sanusi G (2007). The Nigerian biofuel policy and incentives: A need to follow the Brazilians pathway. International Association for Energy Economics. Fourth quarter pp. 35-39.
Onwughara IN, Nnorom IN, Kanno OC (2010). Issues of roadside disposal habit of municipal solid waste environmental impacts and implementation of sound management practices in developing country Nigeria. Int. J. Env. Sci. Dev. 1(5):409-418.
PCA (1979) Technical data handbook on the coconut, its products and by-products. Philippine Coconut Authority. Casein City. Philippines.
Pelling M, Thomas- Hope E (1999). Solid waste management: Critical issues for developing countries. Third World Planning Review 21(1):109-110.
Pereira EG, Da Silva JN, De Oliveira JL, Machado CS (2012). Sustainable energy: A review of gasification technologies. Renewable Sustainable Energy Rev. 16:4753-4762.
Quaak P, Knoef H, Stassen HE (1999). Energy from biomass. A review of combustion and gasification technologies. p 6. World Bank Technical paper. Energy series.
Renewable Fuel Association (RFA) (2011). World fuel ethanol production. www.ethanolrfa.org/pages /world-fuel ethanol-production. Accessed 07/01/13.
Ryan P, Openshaw K (1991). Assessment of biomass energy resources: A discussion on its needs and methodology. In: Energy series paper (IBRD) no 48/ IBRD Washington DC USA. Industry and Energy Department. P. 77.
Sambo AS (2006). Renewable energy electricity in Nigeria: The way forward. Paper presented at the Renewable Electricity Policy Conference held at Shehu Musa Yarádua Centre, Abuja. pp. 11-12.
Schenk PM, Thomas- Hall SR, Stephens E, Marx UC, Mussgnug JH, Posten C, Kruse O, Hankamer B (2008). Second generation biofuels: High -efficiency microalgae for biodiesel production. Bioenergy Res. 1:20-43.
Smith OB (1989). Utilization of crops residues in the nutrition of sheep and goats in the humid tropics of West Africa. In Atta Krah A.N and Reyholds L. Sheep and goat meat production in the humid tropics of West Africa. Yamoussoukro 21-25 September 1987. FAO Animal Production and Health paper. http://www.fao.org/library/library-home/en/
Sun Y, Cheng J (2002). Hydrolysis of lignocellulosic materials for ethanol production: a review. Bioresour Technol. 2002; 83:1-11.
Taherzadeh MJ, Niklasson C (2004). Ethanol from lignocellulosic materials: pretreatment, acid and enzymatic hydrolyses and fermentation. In: B.C Saha, Hayashi K. (eds) Lignocellulose Biodegradation American Chemical Society .Washington DC. p 49-68.
Turkenburg WC (2000). Renewable energy technologies . In: Goldemburg J , Johansson T.B. (eds), World Energy Assessment : Energy and the challenge of sustainability. Chapter 7. UNDP. pp. 219-272.
Unilorin (2012). Jatropha: A goldmine plant. www.new.unilorin.edu.ng/unilorin/index.php/jatropha-plant. Accessed on 30/10/12.
USAID (1989) Baling sugarcane tops and leaves: The Thai experience. August. Office of Energy and Infrastructure. R and D/EI Report No 91-15. Document No PN-ABI-900.
Vimal OP, Tyagi PD (1984).Energy from biomass- An Indian Experience. Agricole Publishing Academy. New Delhi. India. 440 p.
Vimal OP (1979). Residue utilization, management of agricultural and agro industrial residues of selected tropical crops (Indian experience). Proceedings of UNEP/ESCAP/FAO Workshop on Agricultural and Agro industrial residue utilization in Asia and Pacific region.
Yang J, Xu M, Zhang X, Hu Q, Sommerfeld M, Chen Y (2010). Life - cycle analysis on biodiesel production from microalgae: Water footprint and nutrient balance. Bioresour. Technol. doi:10.1016/j.biortech.2010.07.017.