Bioenergy Potential in Nigeria

Francis O. Olanrewaju*, Gordon E. Andrews, Hu Li, and Herodotos N. Phylaktou

Faculty of Engineering, School of Chemical and Process Engineering, University of Leeds, LS2 9JT, United Kingdom
pmofo@leeds.ac.uk, profgeandrews@hotmail.com

The potential of waste agricultural, forest and waste material in Nigeria for energy generation was quantitatively estimated using Nigerian Government data. The current biomass capacity of Nigeria is over 200 billion kg of biomass per year. Wood fuel and charcoal account for over 80% of the energy that is consumed in households in Nigeria for cooking and heating. Wood fuel accounts for about 94% of traditional biomass that is utilized for household cooking in Nigeria. 46 million tonnes of wood fuel was used in 2014 for domestic cooking in the country. The nation's total energy consumption in 2015 was 121 Mtoe. The analysis that was carried out in this work shows that Nigeria has the potential to generate about 62 Mtoe (2.6 billion GJ) of energy from its biomass resources (about 51% of the nation's energy consumption in 2015). The largest resource by far is agricultural crop residues, much of which is currently burnt in the fields. The estimated bioenergy potential of Nigeria's forest residue (8.7 Mtoe equivalent to 363 PJ) is 1.04 times greater than the energy consumed for transportation and four times greater than the nation's electricity consumption in 2015. The costs of transportation energy (pump price of oil products) and electricity in Nigeria are still high despite the huge amount of biomass that is available in the country, from which clean and renewable fuels or energy can be produced. If the abundant bio-resources of Nigeria are harnessed to produce bioenergy, transportation fuels and electricity, then energy will become more affordable and more accessible by the general populace. The power sector of the country will also be stabilized, and electricity supplies provided for rural areas, where the agricultural waste biomass occurs.
Key words: Biomass, biofuels, energy, bioresources, statistics, biogas, waste

1. Introduction

Nigeria is naturally endowed with large quantities of biomass, in waste agricultural crops, forestry and there is also significant energy in waste materials. This work estimates Nigeria's bioenergy and waste resource and their energy generation potentials. The current practice in Nigeria is to dispose of agricultural residues by burning them in the fields. Municipal solid wastes are also disposed of by setting them on fire when waste disposal sites are filled up. These practices result in wastage of energy in the country. The high pump price of petroleum products in Nigeria makes the products inaccessible to the poor and the middle class (the larger portion of the populace). The cost of transportation and the cost of foodstuffs in Nigeria are currently high because of the high pump price of petroleum products. If agricultural residues and wastes are converted to biofuels and blended with oil products, the pump price of petroleum products will reduce. This will in turn lead to a reduction in the cost of transportation and foodstuffs. Also, the emission of environmentally harmful gases from combustion engines will be drastically reduced. Also, solid waste material can be burnt or gasified and used to produce local small-scale electricity in the rural villages where the waste arises.

The industrial and economic growth of any nation requires a reliable power supply. Unfortunately, electricity is not readily available in Nigeria, particularly in rural areas. According to the Federal Government of Nigeria, (FGN) the low per capita consumption of electricity in Nigeria (100 kW as against about 10,000 kW for developed nations) results from low generation of electricity, as well as the challenges of establishing a national grid (FGN, 2006). Owing to the uncertain and intermittent power supply of Nigeria, industries, households and commercial firms have resorted to private diesel or petrol-fueled electrical generators. This development has resulted in the death of over 10,000 Nigerians between 2008 and 2014 from the inhalation of

poisonous carbon monoxide (CO) gas that is emitted from petrol generators (Anyagafu, 2014). This underscores the dire need for the incorporation of clean combustion technologies in combustion engines.

1.1 Energy consumption and supply in Nigeria

Nigeria is a country in West Africa with a population of about 182 million in 2015 and a yearly population growth rate of 2.55%, as reported by the Food and Agriculture Organization (FAO) of the United Nations. The country has a land area of 92,377,000 ha (923.77 billion m^2) from which 70,800,000 ha (708 billion m^2) is used for agricultural purposes (FAO, 2016). The total production and importation of energy in Nigeria for 2015 was 265 Mtoe while the overall consumption was 121 Mtoe as shown in Table 1, based on data from the International Energy Agency (IEA) (IEA, 2015). Table 1 shows that about 85% of total energy consumption in Nigeria comes from wood fuel and charcoal (traditional biomass). This is because the rural communities and the urban poor in Nigeria (the majority of the population) depend on traditional biomass for heating and cooking. According to Sambo (2006), wood fuel and charcoal are utilized for heating and cooking by 80% of Nigerian households in the rural and urban areas. The consumption of wood and charcoal for household cooking in Nigeria in 2014 was 46 and 3.2 million tonnes respectively (UNdata, 2017). This shows that wood fuel accounts for 94% of domestic traditional biomass consumption in Nigerian households. The relatively low consumption of charcoal in Nigerian households compared to wood is strictly related with the local process adopted for charcoal production. The local production method does not favour large scale production of charcoal, which is derived from wood, but is of a higher calorific value and a low yield relative to the original wood.

Table 1: Energy consumption by different sectors in Nigeria

Sector	Oil products		Coal		Natural gas		Biofuels/waste		Electricity	
	Mtoe(EJ)	%	Mtoe(EJ)	%	Mtoe(EJ)	%	Mtoe(EJ)	%	Mtoe(EJ)	%
Industry	0.40(0.02)	5.26	0.00(0.00)	0.00	2.60(0.11)	34.21	4.20(0.18)	55.60	0.40(0.02)	5.26
Transport	8.40(0.35)	100	0.00(0.00)	0.00	0.00(0.00)	0.00	0.00(0.00)	0.00	0.00(0.00)	0.00
Household/ Others	2.70(0.11)	2.62	0.00(0.00)	0.00	0.00(0.00)	0.00	98.70(4.14)	95.64	1.80(0.08)	1.74
Non-energy use	0.00(0.00)	0.00	0.00(0.00)	0.00	1.40(0.06)	100.00	0.00(0.00)	0.00	0.00(0.00)	0.00

Table 1 also shows that 96% of biomass energy is utilized by the household sector in Nigeria. Saeed et al. (2015) reported that the household sector in Pakistan uses 86% of the country's total biomass energy. Thus, households in Nigeria use a larger share of the nation's total biomass energy than households in Pakistan. Both countries have a large rural population with no access to electricity but have agricultural waste that could be used to generate electricity instead of being burnt in the fields.

The policy of the Federal Government of Nigeria on the exploitation of forest resources requires that for every forest tree that is cut down, two trees must be planted, the Cut-one-plant-two policy (Ogunesan, 2017).

Table 1 above shows that 8.40 Mtoe of total oil products (73% of oil products in 2015) was used in the transport sector in Nigeria. Also, 2.70 Mtoe (23.48%) was used in diesel generators for electricity in small and large-scale businesses, organizations and households.

1.2 Previous estimates of Nigeria's bioenergy potential

Previous estimates of the bioenergy potential in Nigeria are given in Table 2, which shows relatively few previous quantitative investigations of the bioenergy potential in Nigeria. Furthermore, the available estimates are not current because they were based on 2010 production data. Therefore, there is a need to estimate the biomass and bioenergy potential in Nigeria using recent production biomass data.

Table 2: Previous estimate of bioenergy potential in Nigeria (Simonyan and Fasina, 2013)

Biomass resource	Biomass weight (billion kg)	Potential energy (GJ)	Production data
Agricultural crops	145.62	$1,958.94 \times 10^6$	2010
Plantation crops	4.47	54.60×10^6	2010
Forest residues	-	0.02	2010
Municipal solid waste	3.17	186.33	2010
Animal waste	15.76	29.25	2010
Human waste	2.59	8.13	2010
Total:		$2,013.54 \times 10^6$ (48.06 Mtoe)	

2. Methodology

The set of data produced in this work was mainly obtained during field work in Nigeria in December 2017. The production figures of major agricultural crops in the country were obtained from the National Agricultural Extension and Research Liaison Services, (NAERLS) and the Federal Department of Agricultural Extension, (FDAE) Nigeria (NAERLS and FDAE, 2014) as well as the FAO (2014).

There were no official estimates for residues that result from agricultural crops in Nigeria. The biomass potential of the crop residues was obtained by multiplying the average values of the production figures of the crops (2004-2014) by their respective residue-to-product ratios (RPR) (Simonyan and Fasina, 2013). The biomass and bioenergy potentials of perennial crop residues were estimated by using the residue percentages reported by Koopmans and Koppejan (1997), wood densities reported by Alakangas (2005) and LHV for wood residues (Wood Energy, 2006). Also, the residue-to-product ratio (RPR) data of perennial crops of Chong and Idrus (1988) were used. The energy potentials of forest residues were estimated based on data obtained from FAO (2015). The bioenergy potential of municipal solid waste (MSW) in Nigeria were estimated based on the waste generation figures reported by Suberu et al. (2013). A biogas yield of 0.21 m^3/kg (Neilfa et al., 2014) and a biogass lower heating value (LHV) of 22.35 MJ/m^3 (Astals and Mata, 2011) were used in the estimation of the bioenergy of the waste. The yield of biogas from dry matter as reported by Jain (1993) was used. The estimation of animal waste was based on animal population data as reported by FAO (2015) and NASS (2012). The yield of biogas from livestock dry matter as reported by Jain (1993) were also used. Biogas LHV of 22.35 MJ/m^3 (Astals and Mata, 2011) was used to estimate the energy potential of the estimated biogas from animal waste in Nigeria. Human waste in Nigeria was estimated based on the figure of Jossy (1994); a dry matter of 0.09 kg per head per day for urban population.

2.1 Estimation of biomass bioenergy potential

The bioenergy potential of agricultural crop residues in Nigeria was estimated using equations 1 and 2.

$$W_r = P.RPR.a \tag{1}$$

$$R_E = W_r.LHV \tag{2}$$

In the equations above, W_r is the available weight of residue (kg), P is production figure of the crop (kg), RPR is the crop's residue-to-product ratio, a is the fraction of residue that is available, R_E is the residue energy (PJ), and LHV is the lower heating value of the residue (MJ/kg). Table 3 displays the parameters that were used in this work.

Table 3: Parameters

Quantity	Value
Biomass to energy conversion efficiency	30% (Simonyan and Fasina, 2013)
Recoverable MSW	60% (Koopmans and Koppejan, 1997)

3. Results and discussion

3.1 Energy potential of agricultural crop residues in Nigeria

The crop production data from which the energy potential of agricultural crop residues in Nigeria was estimated were analyzed and presented graphically as shown in Figure 1 for selected major crops. The calculated crop residue that was available for energy in 2014 was 154 million tonnes of residues. This estimate is 8 million tonnes or 5.2% greater than the estimate of Simonyan and Fasina (2013). The estimated residue energy potential in this work is 49 Mtoe (2,034 PJ). The current estimate is 1.79 Mtoe above the 2010 estimates (Simonyan and Fasina, 2013). If 30% biomass to energy conversion efficiency is applied, the effective bioenergy that is obtainable from crop residues in Nigeria is 1.7% above the estimate of Simonyan and Fasina (2013).

Nigeria has great potentials to increase her bioenergy resources. The cultivated land in Nigeria is 44% of the total area (FAO, 2016). This leaves about 30,000,000 ha of agricultural land uncultivated. If 50% (15,000,000 ha) of the uncultivated land is available for energy crop production, the production of the crops can be increased by about 50%.
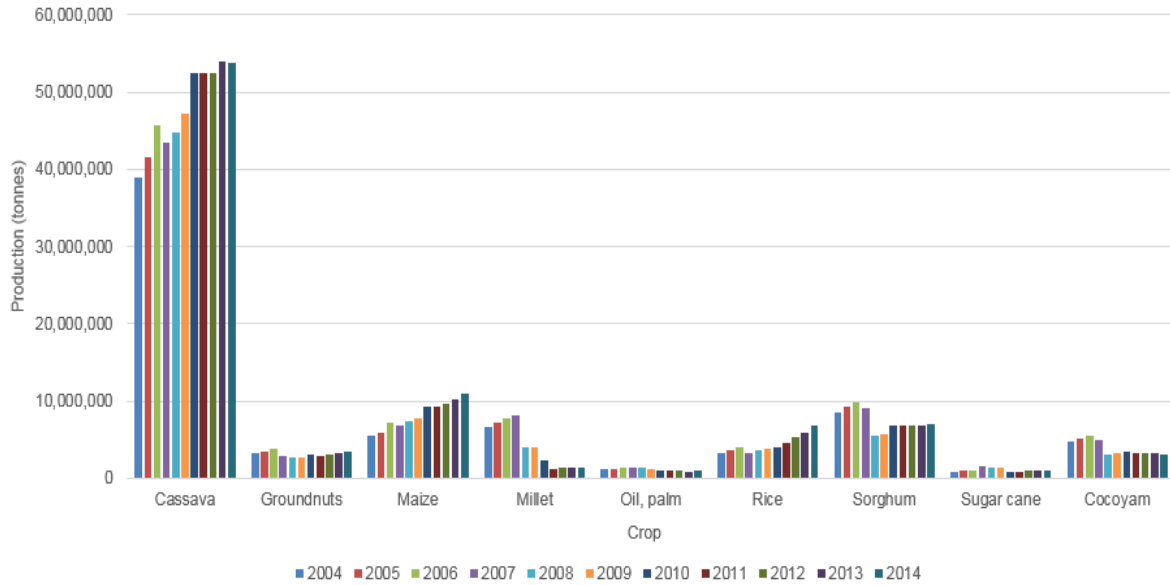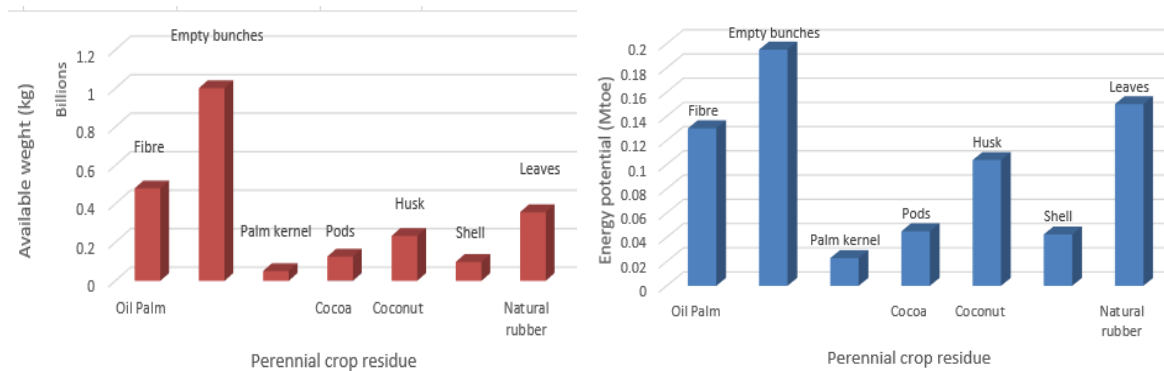
Figure 1: Crops cultivated in Nigeria (2004-2014)

3.2 Energy potential of perennial crop residues in Nigeria

Figure 2 summarises the available mass and residue energy of perennial crops in Nigeria. Figure 2 shows that Nigeria has a perennial crop biomass capacity of about 2.35 million tonnes of residues from which 0.69 Mtoe (28.88 PJ) of energy can be generated.

(a) Available weights of perennial crop residues   *(b) Energy potentials of perennial crop residues*

Figure 2: Biomass and bioenergy potentials of perennial crop residues

3.3 Forest residues

The estimated energy potential of Nigeria's forest residue is about 8.68 Mtoe (363 PJ) which is obtainable from a biomass weight of about 19 million tonnes of forest residues. The estimated energy potential in this work is much higher than the estimate for 2010 in Table 2.

3.4 Municipal solid wastes (MSW)

The yearly MSW potential of Nigeria was estimated to be 17 million tonnes with an organic content of 7.5 million tonnes. Simonyan and Fasina (2013) estimated 3.17 million tonnes of MSW for the urban population of Nigeria in 2010. The estimate was based on the per capita waste generation of Ibadan (a city in Nigeria) as reported by Eisa and Visvanathan (2002). The authors estimated a total recoverable MSW of 1.90 million tonnes of waste based on 60% waste recovery from which 4.45×10^{-6} Mtoe (186.33 GJ) could be generated. However, the estimate in this work was based on MSW data that was obtained from the entire country. The estimated recoverable organic waste from the annual MSW produced in Nigeria is 4.51 million tonnes based

on 60% recovery. The energy potential of the recoverable organic waste is 0.51 Mtoe (21.36 PJ). The MSW estimate of Simonyan and Fasina was 1.9 million tonnes which is 58% lower than the present estimate.

3.5 Animal waste

A total of 18 million tonnes of dry animal dung/year was estimated for 2013 from which the calculated yield of biogas was 4.76 billion m^3/year. The estimated volume of biogas in this work is equivalent to 2.54 Mtoe (106.39 PJ). Simonyan and Fasina (2013) estimated 15.76 million tonnes of dry matter and 4.19 billion m^3 of biogas for Nigeria as of 2010. Ben-Iwo et al. (2016) reported an annual biogas yield of 2.48 billion m^3 based on 0.03 m^3 gas yield per kg of fresh animal waste. Compared with the estimate in this work, these authors have under-estimated the biogas yield that is obtainable from animal wastes in Nigeria.

3.6 Human waste

Given the densely populated nature of Nigeria, the country generates a large amount of human wastes. Based on the figure of Jossy (1994); a dry matter of 0.09 kg per head per day for urban population, Nigeria produced an annual dry matter of 2.87 million tonnes of waste in 2015. The overall estimate of biogas that could be produced from this dry matter was 1.29 billion m^3 (28.83 PJ). The potential yield of biogas from Nigeria's urban population, as estimated in this work, is 1.29 billion m^3 which value is 9.3% larger than the estimate of Simonyan and Fasina (2013).

3.7 Summary of Nigeria's biomass and bioenergy potentials

The summary of the estimated biomass and bioenergy potentials of Nigeria is presented in Table 4. The estimated overall biomass and bioenergy potentials of Nigeria in this work are 200 billion kg/year and 2.58 billion GJ (61.67 Mtoe) respectively. The estimate is 51% of the nation's total energy consumption in 2015.

Table 4: Summary of Nigeria's biomass and bioenergy potentials

Biomass resource	Quantity (billion kg/year)	Estimated energy potential (PJ/year)
Crop residues	153.76	2,033.85
Perennial crop residues	2.35	28.88
Forest residues	19	362.95
Municipal solid wastes	4.51	21.36
Animal wastes	17.69	106.39
Human wastes	2.87	28.83
Overall total	200.18	2,582.26 (61.67 Mtoe)

4. Conclusion

The foregoing analysis has shown that Nigeria's biomass resources are 200 billion kg/year and have the potential to generate 62 Mtoe (2.58 billion GJ) of energy annually. The bioenergy potential of Nigeria's forest residue is estimated to be 363 PJ (8.7 Mtoe or 101 TWh). This estimate is similar to the energy consumed by transport in 2015 and four times greater than the nation's electricity consumption in 2015. If properly harnessed, Nigeria's biomass resources can generate sufficient bioenergy to reduce the pump price of petroleum products in the country as well as stabilize the power sector. The current practice in Nigeria is to set crop residues on fire after harvest to clear the land in preparation for the next planting season. This practice, apart from wasting enormous bioenergy, pollutes the air by releasing Green House Gases, particulates and NO_x into the atmosphere. The use of crop residues in Nigeria for electricity generation will check wastage of the nation's bioenergy as well as keeping the atmosphere cleaner. Bioresources are renewable and so the generation of electricity from biomass will reduce the GHG emissions from Nigeria. Nigeria has the capacity to generate on an annual basis biogas and bioethanol both for local consumption and for export. The potential for Nigeria to increase her bioenergy resources is great as there are vast unused scrub lands in the country which could be used to grow energy crops on a large scale, with no impact on food production. This would provide employment, income and energy for rural villages.

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