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Biofuels: An Alternative Resource for Mitigating Primary Energy Shortfalls in Nigeria

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Abstract *– The present communication examines the techno-economic feasibility of integrating biofuels, particularly biogas, bioethanol and biodiesel into the primary energy mix in Nigeria and dwells on the viability of small, community based electric power plant based on biogas from animal manure as well as size optimization of biodiesel plants in Nigeria. Cost analysis indicates that electricity generation from biogas is environmentally benign and sensible for an integrated farm unit. It is however, not economically feasible in the case of commercial power generation in view of the fact that 1 kWh of biogas derived electric power would cost between €c (12 – 20), which is slightly higher than the present cost of power produced by the state-owned power utility board. Biodiesel plants of more than 20,000 T/y capacity running on cheap vegetable oil feedstocks are associated with relatively lower overall production costs and are likely to be more profitable.*

Keywords – Animal manure, biofuels, electricity generation, power plant, primary energy.

1. INTRODUCTION

Today, the importance of energy in the society cannot be over-emphasized. In a developing country such as Nigeria, energy demand is growing at a fast pace but, similar to other basic amenities, its supply is not guaranteed all over the country, especially in the rural communities. Most of Nigeria's power plants and grid system were installed about three or four decades ago and have not received adequate maintenance over the years. As such they are not able to cope with the present power demands of the country, especially in view of growing population and expanding economic activities.

Nigeria's primary energy demand and supply scenario indicates that woody biomass is still the main source of energy for heat generation (51%) whereas fossil derived petrol; diesel and kerosene continue to dominate transport sector energy needs of the country [1]. Fossil fuels being finite in nature, results to it being generally expensive and often out of reach for average homes. As such they cannot meet the real demand for energy especially for electricity generation as well as fuels for the transport sector of the economy. Again there is a great need to conserve the forest reserves amidst growing desert encroachment and erosion threats in parts of the country, which arise as a direct consequence of deforestation.

Available options for meeting the shortfall in energy supply range from building more grid-based power generation plants (which is capital intensive) to investing in new alternative energy systems**.** In the past few years, there have been plans by the Federal and State Governments to expand the power base of the country by adding nearly 1500 MW to the National grid at a total cost of almost US$2 Billion [2]. Most of these proposed power facilities are still under construction. However, the construction of community based distributed supply plants running on renewable energy resources seems to be a more attractive option in view of the fact that they can be targeted directly at the rural communities, most of which lie far away from the grid. It is now a well-established fact that such plants have numerous advantages over grid systems, which are often cumbersome and rather inefficient in addition to their heavy reliance on fossil fuels. Renewable energy systems are environmentally benign but also well suited for scattered township suburbs and semi-urban communities, which are very common in Nigeria. The present study, therefore, dwells on the possibility of integrating biofuels within Nigeria's energy mix by examining the possibility of community based electricity generation from biogas coupled with the right choice of plant sizes for processing biodiesel fuels from vegetable oils.

Detailed techno-economic feasibility of the biogas-to-electricity approach is examined using the example of similar systems already realized in Italy. The quantity and availability of biomass resources capable of being processed into biogas and biodiesel are evaluated, whereas the cost per kWh of biogas generated electricity is compared to that derived from conventional fossil power both by the public utility -Power Holding Company of Nigeria (PHCN)- and privately operated household generators running on petrol and diesel. Finally, the effect of plant size on the production cost of biodiesel is characterized by simulation studies.

2. ENERGY SITUATION IN NIGERIA

Nigeria has a population of about 132 Million inhabitants and a total landmass of nearly 923,000 Km^2. About 70% of the total population dwells in the rural areas. Traditional biomass (largely wood fuels) accounts for the largest share of total primary energy consumption (51%) followed by petroleum products (41%), natural gas (5.2%)

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and electricity (3.1%) [3]. Although the installed electricity generation potential is about 6,000 MW only 40 % of the total population (82 % in the urban and 10% in the rural areas) have access to electricity, which is rather erratic in supply. Annual electricity demand has been increasing very sharply from 1,273 GWh in 1970 to 13,700 GWh in 2001 [4]. Power supply is furnished by eight (8) power stations, most of which operate on fuel oil, natural gas or diesel and hydropower. There is an obvious need to augment power supply needs in a country where the population is expanding at a rapid rate. The national energy policy seeks to make available reliable electricity supply to 75% of the population by 2020 [4]. In the short term, construction of new large power plants seems a good option to meet such a target although this has economic and environmental implications. In Nigeria, most rural areas lie far apart and are, often, not connected to the national electricity grid. This makes the use of renewable energy technologies more attractive in view of the fact that they could be community-based. Most rural areas are also farmlands, where availability of agro waste materials is very high. Currently, Nigeria relies exclusively on fossil fuels to meet her current demands for transport fuels (8.8 thousand MT of petrol, 3.2 thousand MT of diesel and 1.4 thousand MT of kerosene [5]).

3. RENEWABLE ENERGY RESERVES OF NIGERIA

Nigeria is endowed with large deposits of renewable energy reserves, a lion's share of which is yet to be harnessed into more useful resources. Some of these energy potentials are itemized below:

Solar Radiation

Located close to the equator (Lat. 4 – 14^{o}N) Nigeria receives an average of about 20 MJ/m^{2}day of insolation annually, which translates into about 5.6 kWh/m^{2}day [5]. Although much of the country's energy needs could be met by converting only 1% of the incident solar radiation to electric power using photovoltaic technology [4], the cost implication is quite high. Presently solar radiation is harnessed only for small scale drying operations at farm settlements while other low temperature applications such as cooling, chick brooding/incubation; water heating, etc have been developed and tested at research centers though still awaiting proper diffusion in the country.

Hydro Power

Apart from the Atlantic Ocean, which washes the southern coastlands of Nigeria, two major Rivers –Niger and Benue - traverse most of the hinterlands. Dams for the purposes of power generation have been realized on the two Rivers at Kainji, Jebba and Shiroro, which provide nearly 36% of the country's electric energy. Small-scale Hydroelectric plants (combined output, 734.2 MW) have been constructed on 7 Rivers [5]. Plans are also underway to construct another hydroelectric power station on the Mambila plateau. However, since most rural areas are not connected to the grid system it remains to be seen how they can benefit from hydro-electric energy.

Wind Energy Potential

Wind energy has not been harnessed for the purposes of power production and commercial power plants based on wind energy technology have yet to be realised throughout the country, with the exception of a few demonstrational wind farms realized at research institutes. However, wind speeds of about 3-7 m/s are common in most parts of Nigeria while higher values have been recorded at the coastal areas and in the far north with less vegetation. Wind energy potentials are at best average.

Biomass Reserves

Biomass reserves in Nigeria comprise mostly of cassava (120 x 10^3 ton/yr), crop residue (83 x 10^6 ton/ yr) and animal waste (61 x 10^6 ton/ yr) [5]. Large quantities of vegetable oils, notably palm oil (about 1 MMT/yr), melon seed oil, etc. are also produced annually and the potential for production of new oil crops such as jatropha seed oil is very bright. Whereas crop residues are used extensively as wood fuel, especially in the rural areas, animal wastes are only used as manure and pose some environmental hazards if applied without first extracting the biogas. Although, the generation of biogas from this abundant feedstock has been demonstrated at research centers and universities, the desirable diffusion of this technology has remained generally low. Biogas from animal manure is a promising renewable energy resource due to the fact that it is cheap and easy to produce in addition to being a potential starting point for both heating gas and fuel for electricity generation. Favorable conditions also abound for commercial scale production of bioethanol and biodiesel in the country to augment petroleum products. Bioethanol production form cassava and biodiesel production from vegetable oils are becoming increasingly necessary and these biofuels will play a very important role in the next few years as crude oil reserves dwindle to just 44 years supply [4].

Biogas Potentials

Biogas is produced by the biodegradation of organic material under anaerobic conditions. Thus, it arises from the bacterial decomposition of organic matter in the absence of oxygen (air). Some of the biogas-producing materials (substrates) range from animal dung to household, agricultural and industrial wastes. Interest in biogas derives from the fact that, in addition to being easy to obtain, it has a calorific value of about 20 MJ/m^3 (20-24 MJ/kg), which is almost comparable to that of natural gas (39 MJ/m^3) and much higher than the heating value of producer gas derived from gasification processes [6]. Furthermore, spent slurry has been found to be very good manure, which poses no environmental problems. In Nigeria, identified feedstock substrates for biogas production include water lettuce, water hyacinth, animal dung, cassava peels and leaves, urban refuse (including industrial wastes), agricultural residue and sewage. It has been estimated that Nigeria produces about 227,500 tons of fresh animal waste daily [3]. This quantity of waste could yield up to 6.8 million m^3/yr of biogas. The estimated animal population in Nigeria is presented in Table 1. It is note-worthy that substantial percentages (about 10%) of the chicken and pig populations are reared on a commercial basis. Availability of animal manure in this section is limited to the five species of livestock that are reared commercially, namely chicken broilers, cows, goats, sheep and pigs (Table 2). The average volumes of biogas, which could be produced from a unit mass of each type of animal manure, have been published elsewhere (Table 3) [7], from where an estimate of the energy potential of each type of animal waste could be obtained.

Table 1. Nigerian livestock population estimate [8], [9].

Livestock	Population Estimate (1992) (Thousands)	Population Estimate (2005)* (Thousands)
Chicken	82400	116678
Goats	34500	48852
Sheep	22100	31293
Cattle	13900	19682
Pigs	3500	4956
Donkeys	900	1274
Horses	200	283
Dogs	4500	6372
Cats	3300	4672
Rabbits	1700	2407
Guinea Pigs	500	708
Giant Rats	60	85
Other Poultry (Pigeon, Ducks, Guinea foul and Turkeys)	31900	45170

* 2005 figures were estimated (nearest thousand) based on an average annual growth rate of 3.2 % from 1992 figures.

Table 2. Potential manure production from commercial livestock species [10].

Livestock (average weight)	Population Estimate 2005 (Millions)	Daily Manure Production (kg/animal/day)	Manure Production (tons/day)
Chicken Broilers (1.5 kg)	146.7	0.028	4109
Goat (45kg)	61.4	1.400	85973
Sheep (45 kg)	39.4	10.400	409115
Cow (550 kg)	24.7	32.000	791745
Pig (150 kg)	6,2	21.100	131452

Table 3. Potential biogas production from animal manure [11].

Feed-stock	Quantity (tons/day)	Methane Content (%)	Projected Biogas Yield (m^3/ton)	Total Biogas Yield ($10^3 m^3$/day)
Chicken Manure	4109	60	50 -100	205.5-410.9
Goat Slurry	85973	54	N/A	-
Sheep Slurry	409115	54	N/A	-
Cattle Slurry	791745	53	25	19793.6
Pig Slurry	131452	58	26	3417.8

Although actual experimental trials performed on animal dungs from Nigeria indicate that the percentage of methane in the generated biogas could be improved when using blends of wastes as shown in Table 4, the present study will be based on pure wastes since most of the farms specialize in one type of animal husbandry.

Several plants have been realized in the country for the production of biogas fuel (used for heat generation) from animal manure, even though the production of electricity from biogas is not yet widespread in Nigeria. However, the conversion of biogas to electricity in internal combustion engines of 10 – 100 kW capacity is common elsewhere [7].

These gas engines, though less efficient than bigger capacity (400kW and above) engines are preferred due to the fact that they generally match existing farm sizes.

Large-scale production of electricity from Biogas starts with the gathering of animal waste from a nearby or integrated farm. Most of the process involves conversion of the raw droppings into an enriched semi solid paste or “slurry” for easy conversion in a digester [12]. Animal waste from the farm is pumped through pipelines into a storage tank before passing through narrow pipes for poly-ionization and de-aeration treatment. These operations facilitate the separation of the solid and liquid phases. The final separation is achieved in a downstream flotation separator, from where the liquid is recycled to the farm for easy transportation of fresh waste material. The solid phase is treated in a rotary drum separator to remove the unwanted solid chaff, which is used as manure. A simplified flow diagram of a typical Biogas plant is shown in Figure 1.

Table 4. Chemical composition of biogas from various blends of animal waste

Waste Type	Biogas Yield L/kg	CH_4 Content %	CO_2 Content %	N_2 Content %
Pure Goat	1.72	60.01	31.19	8.81
80% goat/20% cow	2.08	68.58	26.86	4.56
70% goat/30% cow	2.15	63.51	26.86	4.27
60% goat/40% cow	2.31	64.15	34.42	1.46
Pure Cow	3.30	74.83	25.17	NQ
30% cow/70% swine	1.65	66.79	32.24	0.97
40% cow/60% swine	2.48	58.88	40.96	0.16
50% cow/50% swine	0.99	57.83	40.46	1.70
Pure Swine	0.13	66.93	32.39	NQ

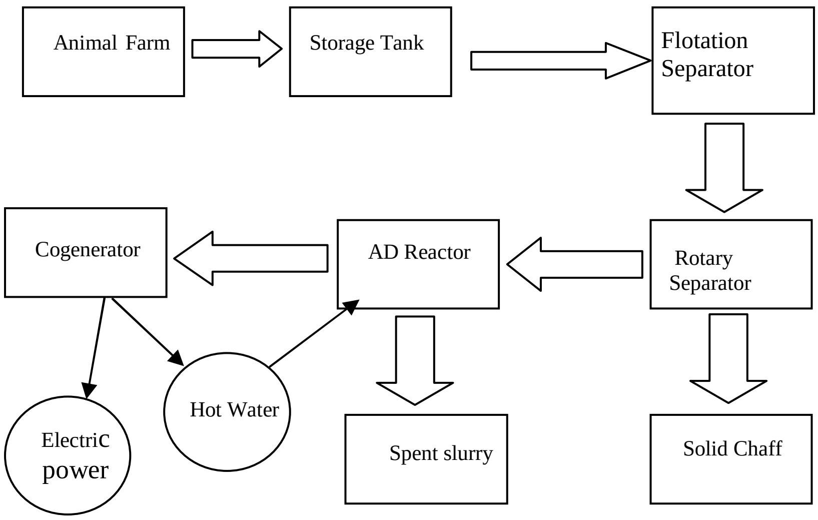

Fig. 1. Simplified flow diagram of a biogas plant. Source: [7]

4. COST ANALYSIS

To assess the overall potential of farm based electricity generation from biogas, it is necessary to determine the cost of a kWh of electricity produced using the proposed method. Feedstock considered here is cattle manure, which has been found to be more available in Nigeria than other types of animal dungs (Table 3). The average size of most herds in Nigeria is about 1,000 cows. This is used as a case study as follows:

According to Tables 2 and 3, this animal population (1,000 cows) is capable of producing about 32 tons of solid manure, or about 800 m^3 of biogas daily. Based on nomographs developed by [7], the produced biogas quantity can generate about 475 MWh/yr of electric energy when used to run a 92 kWe (222kWt) cogenerator for 5000 hours per annum. This is on the assumption of an electrical efficiency of 25 % for the cogenerator and a lower calorific value of 23 MJ/m^3 for the biogas. The thermal power generated simultaneously would be about 1150 MWh/yr, which can be used to produce hot water for different applications (*i.e.* a total power output 1,625 MWh/yr).

The estimated installed cost of the cogenerator is about €123,500.00, whereas the entire plant is estimated to cost about €350,000 [7]. According to figures made available by the state-owned National Electric Power Authority (NEPA), 2002 production cost of electricity in Nigeria is about €0.07 (11 Nigerian Naira) per kWh whereas privately produced power costs € 0.11 (19 Naira) per kWh on the average [13]. The current figure for privately generated power is expected to be about € 0.16 owing to recent increases in the prices of both diesel and petrol.

In the event of running the cogenerator for a total of 5,000 hours per annum the production cost of 1kWh would amount to € 0.14, which is slightly high relative to the cost of equivalent energy produced by the electricity utility board. However, this cost of production is quite competitive relative to the cost of privately produced electricity and also in case of running the engine for more than 5,000 hours per annum. Further, for a farm that is engaged in meat and diary production, the real benefit would be derived from the energy utilized for internal needs coupled with the envisaged predictability in power supply. Total power output and payback time based on internal rate of return (IRR) are also determined for other farm sizes ranging from 500 to 1,200 cows as shown in Table 5.

5. BIOETHANOL POTENTIALS

Nigeria requires about 8.8 thousand MT of petrol annually, which is currently being furnished by four refineries processing fossil crude oil. However, as these resources dwindle the production and utilization of bioethanol blended petrol will ultimately become necessary. Bioethanol production from cassava and other starchy raw material is becoming increasingly important in the country. Currently Nigeria produces 120,000 tons of cassava annually although a lion's share of this quantity is demanded as food since processed cassava is a staple food in Nigeria. A number of plants have been constructed in the past few years and many more are being planned by government and private outfits to produce bioethanol via enzymatic fermentation of cassava [14]. The blending of bioethanol in fossil petrol will ultimately help to conserve the country's fossil reserves even though this will require engine carburettor modifications.

Table 5. Cost analysis of a biogas plant

Farm Size (Number of Cows)	Manure Production (tons/day)	Biogas Yield (m^3/day)	Total Power Output (MWhr/yr)	Payback Time (Years)
500	16.0	400	790	15.06
800	25.6	640	1250	9.52
1000	32.0	800	1625	7.32
1200	38.4	960	1930	6.17

Analysis was based on a plant cost = 350 x 10^3 Euros, Euro value of ₦170 and a power tariff of ₦5.00/kWh.

Table 6. Plant costs of biodiesel processing units based on size [20]

Plant Size (10^3 tons/yr)	8.0	12.5	20.0	40.0	60.0	120.0
Processing Unit Cost (10^6 Euros)	2.63*	3.15*	3.80	4.30	5.10	6.83*
Piping, Reservoir and Instrumentation (10^6 Euros)	0.65	0.89	1.67	3.00	3.83	7.42
Miscellaneous (10^6 Euros)	0.26	0.31	0.38	0.43	0.51	0.68
Total Cost (10^6 Euros)	3.55	4.35	5.85	7.73	9.44	14.93
Annual Amortized for 10 years at 10% p.a. (10^6 Euros)	0.56	0.69	0.93	1.23	1.50	2.37

Fig. 2. Plot of biodiesel plant cost as a function of size

6. BIODIESEL POTENTIALS

Nigeria's annual diesel demand is put at about 3.2 thousand MT of petrol annually. Research work aimed at exploring the potentials of different vegetable oil raw materials into biodiesel has been carried on in Nigeria since the past few years and results indicate that its production from cheap oil feedstocks is quite competitive [15]. Although the most important consideration in biodiesel cost analysis is the feedstock, which accounts for well over 70% of the total production cost, some authors have shown that the type of process as well as plant size also have an immense effect on the final production cost of biodiesel [16]. For instance, whereas the production of biodiesel from animal fats in a 10,560 tons/yr plant facility leads to a breakeven price of $420 /ton [17], [18] the use of Canola oilseed in a 7,800 ton/yr plant culminates in a breakeven price as high as $763/T for the biodiesel product. It becomes apparent that the type of raw material being processed determines the type of equipment to be used, which in turn has a direct effect on the initial fixed capital costs. As a rule, acid-catalyzed transesterification processes are more expensive, since they require the use of stainless steel in most of the plant parts [15]. The processing of animal fats into biodiesel in Nigeria is not feasible owing to the limited availability of animal fats in the country. However, large quantities of vegetable oils such as palm oil, palm kernel oil, melon seed oil etc including proven potentials for jatropha oil are available in the country.

To underscore the effect of capital costs on the final cost of production of biodiesel, six different plant sizes namely; 8,000 tons/yr, 12,500 tons/yr, 20,000 tons/yr, 40,000 tons/yr, 60,000 tons/yr and 120,000 tons/yr of biodiesel product, were simulated using the process simulation software "CHEMCAD version 5.2". Equipment requirements were then harmonized with information obtained from existing plants in Europe as well as available data from literature [17], whereas cost estimations including utilities requirements (Table 6) were provided by experienced vendors in addition to figures available from literature [19]. Plant costs based of the various sizes of processing unit are presented in Table 6 whereas the overall simulated cost of production of biodiesel is plotted in Figure 2. These indicate that plant costs of 20,000 tons/yr capacity plants and above are relatively lower.

7. CONCLUSIONS AND RECOMMENDATIONS

Electricity generation from biogas is an important option in Nigeria, in view of insufficient power supply from conventional fossil sources. Averagely-sized animal farms are capable of generating enough electric power for their needs. However, such projects are not economically feasible in the case of power generation meant purely for commercial purposes since 1 kWh of biogas generated electric power would cost between €c (12 – 20), which is slightly more than the present cost of power produced by the state owned power utility board. However, the estimated cost of biogas generated kWh of electricity compares favorably with current figures for private sector electricity generation from fossil fuels. The use of petrol and diesel blended with some quantity of bioethanol and biodiesel, respectively, is capable of prolonging Nigeria's fossil reserves. Biodiesel plants of over 20,000 tons/yr capacity are associated with lower overall cost of production, especially when using cheap vegetable oil feedstocks.

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