# JOURNAL OF ENERGY POLICY, RESEARCH AND DEVELOPMENT

# (JEPRD)

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**Published**
**BY**
## ENERGY COMMISSION OF NIGERIA
**Volume 1, No 1, MARCH, 2011.**

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# TABLE OF CONTENT

# EDITORIAL

The Energy Commission of Nigeria (ECN) was established by Act 62 of 1979 and its subsequent amendments with the responsibility for the strategic planning and coordination of national policies in the field of energy in all its ramifications. In doing so the Commission, inter alia, is to serve as a centre for gathering and dissemination of information relating to national policy in the field of energy development; collate, analyze and publish information relating to the field of energy from all sources; and to make recommendations for the exploitation of new sources of energy to the Government. Accordingly, the Energy Commission of Nigeria is publishing an international Journal, ***JOURNAL OF ENERGY POLICY, RESEARCH AND DEVELOPMENT (JEPRD),*** in order to accomplish its mandate.

JEPRD is to serve as the vehicle for the dissemination of research and developmental efforts and strategic policies on energy in Nigeria as well as from other parts of the world, deemed relevant to Nigeria's energy development. The Journal will be published bi-annually with the main objective of bringing together research findings and policy strategies in all aspects of energy and also to serve as forum for experts to provide, receive and exchange information to foster the growth and better utilization of energy in all its ramifications.

In this maiden issue, the Editorial Board decided to solicit papers from Energy Commission of Nigeria, its six Energy Research Centers and some eminent scholars in the field of energy. Consequently, this issue has nine articles featuring on various aspects of energy. The first paper is a contribution from Professor Sambo, A. S, who is the Director General, Energy Commission of Nigeria and Vice Chair, World Energy Council-Africa (WEC-Africa). The paper highlights the energy outlook of Nigeria's energy demand over a period of 30 years, in which bottom-up analysis of Nigeria's energy demand over the period 2005 – 2030, conducted by Energy Commission of Nigeria, for meeting the socio-economic development aspiration of Nigeria. The energy requirements for the country's development aspirants were assessed within the framework of scenario analysis by using the Model for Analysis of Energy Demand (MAED), which was developed by the International Atomic Energy Agency (IAEA).

The second paper is a contribution from Dr. Abubakar, M. B., who is the Acting Director, National Centre for Petroleum Research and Development (NCPRD), Abubaka Tafawa Belewa University, Bauchi. The paper dwells on petroleum exploration potentials in the northeastern Nigerian sedimentary basins (the Gongola and Borno Basins). It articulates three potential petroleum systems that have been identified and could prove very effective in planning future exploration campaigns. The evaluation of the petroleum potentials of these basins also reveals numerous exploration challenges that require effective and dynamic strategies, and new perspectives and exploration concepts away from those applicable to the Niger Delta.

The third paper is a contribution from Dr. Akinbanmi, J. F, K and Mr. Momodu, A. S., who are very senior Research Officers of the National Centre for Energy Research and Development (NCERD), Obafemi Awolowo University, Ile-Ife; while the forth paper is a contribution by Prof. Fagbenle, R. L, an energy expert, from the Mechanical Engineering Department, University of Ibadan. The Fifth paper is a contribution from Dr. Garba, M. M and Dr. Danshehu B. G, who are also very senior Research Officers of the Sokoto Energy Research Centre (SERC), Usmanu Danfodio University, Sokoto. These three papers highlight the use of renewable energy for increased energy access and climate change mitigation. The sixth paper is a contribution from Prof. Adegbenro, O., who is the Director, National Centre for Energy Efficiency and Conservation, University of Lagos. The paper looks at the challenges and prospects of energy efficiency and conservation in Nigeria. The seventh paper highlights work done on the transesterification of palm oil, Jatropha and Neem seeds oil for biodiesel production in Nigeria; and it is a contribution from Dr. Okonkwo, E. M et al, who are actively involved in Research and Development in biofuels at the National Research Institute for Chemical Technology, Zaria. An overview of nuclear energy activities in Nigeria is presented in the $8^{th}$ paper; and is a contribution from Prof. Jonah, S. A, who is a very senior Research Officer at the Centre for Energy Research and Training (CERT), Ahmedu Bello University, Zaria. The $9^{th}$ paper evaluates the fiscal regimes in the Petroleum Industry Bill in Nigeria; and is a contribution from Engr. Olayande, J. S., who is a Deputy Director, Energy Commission of Nigeria.

Subsequent editions of the Journal will be opened to scholars, researchers, policy makers, entrepreneurs and students in the energy sectors to make submission inline with the guidelines provided in Instructions to Authors at the back of this issue, for consideration for publication. All papers submitted to JEPRD will be peer reviewed before they are published.

The support of the Director-General/Chief Executive of the Energy Commission of Nigeria, Professor A. S. Sambo OON, NPOM, towards the establishment and publication of this maiden issue of the Journal is hereby acknowledged by the Editorial Board.

**Prof. Eli Jidere Bala**
**Editor-In-Chief**

Journal of Energy Policy, Research and Development
Vol. 1, No1, pp (1-17), March, 2011. 

# Nigeria's Long Term Energy Demand Outlook to 2030

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## ABSTRACT

In recent times, various national plans aimed at accelerating the socio-economic development of the country were articulated. These include the National Economic Empowerment and Development Strategy (NEEDS), which is the country's strategy for achieving the Millennium Development Goals (MDG) of the United Nations (UN), the Seven Point Agenda and the Vision 20: 2020. The Energy Commission of Nigeria is required by law to prepare, review and update national plans periodically to ensure that all reasonable demands for energy are met in a sustainable manner. In conformity with this mandate, the Energy Commission of Nigeria evaluated the energy implications of the development plans to prepare this Energy Demand Outlook covering the period 2005-2030. Such analysis will enable the design of appropriate policies, plans and programmes, which will ensure security of energy supply in the right quantity and quality for the economy. This paper presents the results of the detailed bottom-up analysis of Nigeria's energy demand and supply over the period 2005 – 2030 towards meeting the socio-economic development aspirations of the country encapsulated in the development plans. The energy requirements for the country's development aspirations were assessed within the framework of scenario analysis by using the Model for Analysis of Energy Demand, which was developed by the International Atomic Energy Agency. The model follows the end-use demand forecasting steps typical of an engineering-economy model. The total final energy demand is projected to increase from 32.5 Mtoe in 2005 to 80Mtoe by 2010, 202.74 Mtoe by 2020 and 747.27 Mtoe by 2030 for the Optimistic scenario, which represents the projections for Vision 20:2020. All of these require strong policy support and commitment. Sustainable electricity generation will require a range of technologies, including natural gas, hydro, advanced coal-fired generation, nuclear and non-hydro renewables.

## 1.0 INTRODUCTION

In recent time, Nigeria envisioned various development plans aimed at accelerating the socio-economic development of the nation. These include the National Economic Empowerment and Development Strategy (NEEDS), which is the country's strategy for achieving the Millennium Development Goals (MDG) of the United Nations (UN), the Seven Point Agenda of the current administration of focusing intensive actions on some specific sectors of the economy such as infrastructure development, food security, human capital development, and the Vision 20:2020 which aims at substantial improvement in the Human Development Index (HDI) rating of the country as well as growing the economy such that Nigeria will be in the league of the twenty (20) largest economies in the world by year 2020. Energy is a key driver of economic growth and social progress because it is required for fuelling industry, powering infrastructure, transportation of goods, people and services to markets and delivering basic services such as heating, cooling, lighting and cooking. Energy being an essential input for economic growth, Nigeria needs to provide sufficient and reliable energy to be able to achieve the socio-economic development aspirations. In conformity with its mandate, the Energy Commission of Nigeria evaluated the energy implications of the development plans to prepare this Energy Demand Outlook covering the period 2005-2030 for the various sectors of the economy and by energy form. To the best of our knowledge, there is no study to date, which provides scenarios of energy demand in Nigeria by sector and by energy type for the developmental aspirations considered and for a period as long as 25 years as done in this study.

Currently, the World Bank's ranking of economies of countries of the world places Nigeria in the 38$^{th}$ position on a Purchasing Power Parity (PPP) basis (World Bank, 2008). To move to the 20$^{th}$ position by 2020, Nigeria needs to grow its economy at an average rate of 13% p.a. from the present growth rate of about 6% (ECN, 2008).

Manufacturing and services sectors are expected to be the major drivers of the growth. Nigeria needs to significantly upgrade the quality and size of its energy infrastructure in ways that are environmentally and socially sustainable to power the achievement of the goals. The quality of energy services cannot be inferior to the equivalent services provided by the established system; rather it must have the potential of becoming significantly better (Olayande et al, 2008). Supply densities must match demand densities.

Presently, the supply of modern energy, especially electricity, kerosene and diesel is grossly inadequate and there is so much dependence on traditional fuels by the rural dwellers and the urban poor who account for about 60% of the population (FRN-NPC, 2007). Energy-induced environmental degradation is already prevalent in the country (Sambo, 2009). This is characterized by deforestation as a result of felling of trees for fuelwood and charcoal production, air pollution in urban areas arising from vehicular emissions and the burning of traditional fuels for cooking in households, noise pollution from use of small generators to provide electricity due to inadequate supply from the national grid, and land and water pollution from oil spillages in the oil producing communities (Adegbulugbe et al, 1992). These impact negatively on the quality of life of the population and hence on the development aspirations. The principal objective of the study is the evaluation of the energy requirements for the development aspirations of the country and assessment of alternative paths and strategies for the development of the energy and electricity sector to meet the future demand of energy and electricity in the country.

The organization of this paper is such that section 2 is a brief discussion of the historical patterns of energy consumption with emphasis on the last five years preceding the base year of the study, in order to understand the trends in energy consumption and identify sustainability issues in the energy demand and supply chain in the country. Section 3 discusses the methodologies for projection of energy demand and sustainable supply strategies, while Section 4 contains the results and the discussion of the results. The conclusions and recommendations are presented in Section 5.

## 2.0 PATTERNS OF ENERGY CONSUMPTION AND SUPPLIES IN NIGERIA

Appraising future energy demand for Nigeria requires a clear picture of the structure of energy consumption. This picture must include both the quantities of energy consumed by source and the activities or output for which energy is used (Eric et al, 1995).

Prior to the 1960s, energy demand and consumption constituted, very predominantly, of traditional energy sources, namely, fuelwood, charcoal, agricultural wastes and residues and solar radiation. The major commercial fuel was coal, which was used by the railways and for power generation. Modest contributions came from petroleum products (petrol and diesel) and electricity from coal and diesel generators (ECN, 2003).

The structure of energy demand has drastically changed since then. Commercial production of crude oil started in December 1957, with the first exports in 1958. Coal production peaked in 1959 and has continued to decline since then, due in part to the introduction of diesel-powered engines in the railways in the 1960s and eventual stoppage of power production from coal. The first gas turbine power plant was built at Afam, near Port Harcourt, in 1965 with an initial capacity of 56 MW. The first domestic refinery was also commissioned in Port Harcourt in 1965, with a capacity of 60,000 bpd. Furthermore, the first hydroelectric power plant, Kainji, started operations in 1968 with an initial capacity of 320 MW. These developments signaled the beginning of the change in the structure of the energy sector from coal to petroleum dominance of commercial energy. They also signaled the beginnings of the eventual dominance of the economy by the energy sector, especially by the oil and gas sub-sector. Figure 1 shows the consumption of primary energy source types over the period 2001 – 2005.

Up to the end of the last decade, fuelwood and charcoal provided the single largest share of primary energy consumption in the country (FGN, 1992). Over the period 2001-2005, the share fluctuated within the range of 32-40%. About 95% of the total fuelwood consumption was used in households for cooking and for cottage industries. A smaller proportion of the fuelwood and charcoal consumed was used in the service sector (restaurants, schools, prisons, etc). The next most highly consumed primary energy resource was petroleum products (31%), consisting mostly of premium motor spirit (PMS) and automotive gas oil (AGO) generally referred to as petrol and diesel for transportation and power generation, but also including kerosene (household and services), aviation kerosene (transport), fuel oil (industry), liquefied petroleum gas (household and services), as well as lubricating oil, bitumen and asphalt (construction). By 2000 however, natural gas surpassed petroleum products and by 2005, it contributed about 34% to total primary energy consumption (next to fuelwood's 37%). Up to 1999 natural gas was mostly used for power generation. As from 2000, however, the use of the gas as feedstock for liquefied natural gas production for export became predominant. There is also an increasing use of natural gas for thermal applications (steam production) and feedstock to other industries in the manufacturing industry. Combined use of gas in LNG, power generation and industrial heating is expected to terminate gas flaring, which was 54% in 2008. The share of oil product consumption by types in 2005 is shown in Figure 2 with PMS consistently accounting for more than 50% of the consumption over the period.

## 3.0 ANALYTICAL APPROACH

The ECN took advantage of the energy models already developed by the IAEA that provide framework for systematic analysis of various issues covering social, economic, technical and environmental aspects of energy decisions (IAEA, 2006). The International Atomic Energy Agency (IAEA), under Regional Cooperation Agreement, supports projects to carry out studies in member countries to address planning issues of nuclear power. Application of the MAED requires detailed information on demography, economy and energy consumption. The information is first assembled for a base year which is a year in recent past used as the reference year for perceiving the evolution of the country's energy system in order to gain an insight into the energy demand, consumption and supply patterns for the economy in consideration. This will enable comparison with the past consumption and the knowledge gained in addition to anticipated socio-economic and technical growth scenarios will enable projection for the future years. The period considered for the study is 2005-2030 in five year stages.

### 3.1 THE STRUCTURE OF ENERGY CONSUMPTION IN 2005

Identification of sustainable paths and policies for energy sector development in Nigeria requires a clear picture of the current structure of energy consumption and historical development (Eric 1995), which would help provide insight into how these may evolve in the future. In this section, the energy consumption structure for the base year of the study, 2005 is discussed. The primary data sources were aggregated annual energy consumption data from primary data sources, such as the Nigerian National Petroleum Corporation (NNPC), the Power Holding Company of Nigeria (PHCN) and secondary data from the Nigerian Bureau of Statistics (NBS) and the Central Bank of Nigeria (CBN) (Iloeje et al 2003). The Presidential Committee on Alternatives to Fuelwood (FGN, 1992) provided data on fuelwood consumption in Nigeria. This was used in conjunction with the national population figures to obtain the national fuelwood consumption in 2005. Charcoal utilization was provided by the Food and Agriculture Organization (FAO, 2008) of the United Nations. The electricity consumption reported is the sum of consumption from the grid electricity and the consumption from electricity generation by individuals, industries and establishments to meet essential services in the absence of grid electricity. Electricity generated by the industrial, services and residential sectors was estimated as 5% of grid electricity consumption (ECN, 2004)

Dissaggregation of data into sectoral levels was achieved through extensive field work, surveys and interviews, quantitative analysis, analytical models and comparison with countries in similar development stages with Nigeria (Sambo et al, 2006). Table 1 shows the structure of energy consumption in 2005. This table was prepared to construct the energy consumption pattern for the MAED model, details which can be obtained in the Energy Commission's full reports (ECN 2004, 2008).

Out of the total final energy demand of 32.5Mtoe, households accounted for the highest consumption with 56.86%, transportation 28.43%, manufacturing 6.43%, services 8.06% while agriculture, construction and mining jointly accounted for the balance of 0.39%. Traditional fuels accounted for the highest consumption with 49.14%.

The traditional fuels, which include fuelwood, charcoal, crop residues and animal droppings, are consumed largely for cooking and water heating in rural and sub-urban households with small quantities consumed in the services sector also for cooking while some cottage industries, such as bakeries and other food processing also use it in the manufacturing processes. The high proportion of energy consumption in the households is due to the consumption of low quality traditional fuels with low efficiency of utilization. Fossil fuels used for transportation follow with 9.98%, electricity with 5.03%, fossil fuels used for thermal purposes accounted for 4.21% while coking coal and feedstock accounted for the balance. Soft solar (solar thermal applications) contribution was practically zero.

Feedstocks in this study represent energy sources used for non-energy purposes in the manufacturing sector only. Survey conducted by the ECN (Iloeje et al, 2003) indicated that LPG is used as propellants in the manufacture of aerosols such as insecticides and perfumes. Similarly, DPK is used by some pharmaceutical companies to wash their bottles prior to further cleaning with soap and detergents. Coking coal is used in steel manufacturing as reducing agent instead of energy purposes.

From the foregoing, it is clear that the current energy system in Nigeria in which traditional fuels account for a very high proportion of energy consumption is not sustainable. Traditional fuels cannot power the industrialization of the country. Electricity supply is grossly inadequate to support the development aspirations with only 151.3kW per capita consumption. Dependence on hydropower is insecure as a lot of evaporation takes place in the reservoirs and availability is subject to weather conditions and natural gas is a depletable resource.

## 3.2 METHOD OF ENERGY DEMAND ANALYSIS

The Model for the Analysis of Energy Demand (MAED) has been used for the projection of energy and electricity demand in the long-term (2005-2030). It is a widely used bottom-up model for forecasting medium to long-term energy demand and runs on PCs using EXCEL software (World Bank, 2010). MAED is a simulation model that uses a bottom-up approach. The model allows the breakdown of the country's final energy consumption into various sectors and within a sector into individual categories of end-uses in a consistent manner. The breakdown helps in the identification of the social, economic and technical factors influencing each category of final energy demand in the residential, commercial, agriculture, transport and industrial sectors of the economy. For example, in the residential sector electricity is used for cooking, air conditioning, refrigeration, and lighting, and in agriculture for irrigation and on farm processing. The end-use method is based on the premise that energy is required for the service that it delivers and not as a final good. The end-use energy accounting models with detailed sector representation produce more realistic projections compared with econometric models (World Bank, 2009) for medium-to-long term projections.

In the MAED methodology, the industry includes agriculture, construction, mining and manufacturing sectors of the economy. The energy demands of these economic sectors are driven by the economic growth (value added) of the respective sector and the national priority for the development of certain industries or economic sectors. Movement of goods and passengers are the main activities of the transport sector. The driving parameters are tonne – kilometre for freight transport and passenger – kilometre for passenger transport respectively. People's mobility and preferences for transport modes also determine passenger- kilometers. The end-use energy categories of the household sector are air-conditioning, water heating, cooking and electricity for appliances (refrigerators, television, sound system, electric irons, lighting, washing machines, etc.) and space cooling and heating. The factors determining the energy demands of the household sector are related to demography, e.g. number of dwellings, number of persons per household and living conditions (life style) e.g. hot water requirements per person, dwellings with air-conditioning. For the services sector, MAED model projects energy and electricity demand on the basis of floor area and the specific consumption for each end-use. Evolution of the efficiency of certain types of equipment, market penetration of new technologies or energy forms are also parameters that determine future energy demand. The expected future dynamics for these determining factors are exogenously introduced. Equation 1 is the generic demand projection method of MAED (IAEA, 2006).

$$E_i = e_i * VD_i = e_o * F_i * VD_i \text{------------------------------} (1)$$

where $E_i$ is energy demand in year i by sector or by energy form; $e_o$ is base year energy intensity, or energy consumption per unit of VD in the base year; $e_i$ is the energy intensity in year i; $F_i$ is modifier of $e_o$ for year i and it depends on factors such as penetration of technology, energy use efficiency, economy, life style, demography, etc, in year i relative to the base year; and $VD_i$ is value of the driving parameter of energy demand in year i. This, when summed over different end-uses in a sector, gives the aggregate energy demand.

This takes into account improvements in efficiency of energy use, utilization rates, inter-fuel substitution, etc. in a sector as these are captured in the energy required by an appliance. In the process the approach implicitly captures the price, income and other economic and policy effects as well (GOP, 2010). Through scenarios, the model specifically captures structural changes and evolution in the end-use demand and markets.

### 3.3 INPUT DATA AND MAJOR ASSUMPTIONS

Realizing the fact that the 13% target growth rate of the economy envisaged by the government is very high, three possible scenarios of the development of the economy were considered for the energy demand projection to provide alternative views for the decision makers. These are, the Reference Scenario with 7% average GDP growth rate, which represents the most plausible growth scenario without policy changes. This is based on the observation that the average GDP growth over the period 1995 – 2005 was about 7.40% per annum (National Bureau of Statistics, (2008), CBN (2005, 2008), High Growth Scenario with 10% average GDP growth rate and Optimistic Scenario with 13% average GDP growth per annum all over the period 2005 – 2030. Table 2 presents the composition of the real GDP for each scenario in 2020 and 2030 (ECN, 2008). Agriculture accounted for the largest share of 41.19% in 2005, while manufacturing accounted for 3.39%.

Based on the national population census conducted in 2006, the population of the country in 2005 was calculated to be 137.49 million people with the inter-census (1991 – 2006) growth rate of 3.16% per annum. Government's plans to stabilize the population growth rate at 2% per annum (NPC, 2010) has not been achieved, hence the growth rate of the population is assumed to increase to 4.00% by 2020 and thereafter decline to 3.74% per annum in 2030 as a result of the desire for improvements in the quality of living. The assumed evolution of the population growth rate and other demographic parameters which are drivers of energy demand are presented in

Time series data on stock of vehicles in Nigeria is not available. However, based on data obtained from the National Bureau of Statistics on newly registered vehicles in Nigeria, stock of vehicles in 2005 was estimated as 2,508,150 (ECN, 2008). Cars accounted for 42.32%, motorcycles 47.27%, minibuses 2.47%, medium buses 1.24% and luxury buses 0.41%. Freight vehicles (vans, pick-ups, tippers, trailers, tankers) accounted for the balance of 6.3%. In 2005, total freight activity was estimated as 140.88 billion tonne –km, while passenger activity was estimated as 177.72 billion passenger-km. The freight activity is projected to increase to 803.28 billion tonne-km and 2793.53 billion tonne-km by 2020 and 2030 respectively for the optimistic. These and the contributions by various modes of freight transportation are presented in Table 4. In addition, the projections for passenger activity and contributions from cars, buses, train and plane are also presented in

The developments of energy consumption in the household sector up to 2030 are presented Table 5. Electricity penetration is assumed to increase from 55.2% to 93% and 100% in 2020 and 2030 respectively for the Optimistic scenario. Other drivers of energy demand such as electricity consumption per household, electricity penetration into cooking are also presented. Similarly, the evolution of drivers of energy demand in the services sector is presented in Table 6. Floor area per employee is expected to increase from 16.2 $m^2$ to 17$m^2$ and 17.2$m^2$ in 2020 and 2030 respectively for the Optimistic scenario. Cooling requirement is expected to increase from 135 kWh/$m^2$ /yr to 274 kWh/$m^2$ /yr and 310kWh/$m^2$ /yr in 2020 and 2030 respectively for the Optimistic scenario.

## 4.0 RESULTS AND DISCUSSIONS

The total final energy demand projections over the period 2005 -2030 for the three scenarios are presented in Table 7. The total final energy demand of 32.5Mtoe in the base year will increase to 224.54Mtoe, 456.96Mtoe and 747.27Mtoe in 2030, for the reference, high growth and optimistic scenarios, respectively. The projected energy consumption values include traditional fuels, and kerosene (fossil fuel) demand for lighting mostly in household and the services sectors. The average annual growth rates of the total final energy demand over the period 2005-2030 are 9.46%, 13.97% and 17.94% for the reference, high growth and optimistic scenarios respectively. The increase in the growth rates of energy demand for the reference, high growth and optimistic scenarios are due to additional energy requirements for increased economic activities especially with manufacturing sector making more contributions instead of current dependence on importation for virtually everything, increasing access to electricity by all the sectors of the economy, increasing mechanization and automation of the industrial sectors.

Table 8 presents the various forms of the projections of total final energy demand for the three scenarios. In the base year, traditional fuels provided the highest energy demand with 11.66 Mtoe, which constituted a share of 35.88% while modern energy consumption amounted to 20.84Mtoe, representing 64.12% of the total. Petroleum products used for transportation purposes followed fairly closely with 9.98Mtoe or 30.71%. Fossil fuels (petroleum products, natural gas, coal) used for thermal applications constituted 4.57Mtoe (14.06%) while electricity, coking coal and feedstock accounted for 5.93Mtoe, 0.09Mtoe and 0.27Mtoe , that is, 18.25%, 0.28% and 0.83% respectively of the total energy consumption in the base year. Solar thermal and solar photovoltaic applications (that is energy from commercial or engineered solar technologies, excluding the open-to-sun or natural use of solar radiation), made no significant contribution in that year. Solar energy is projected to make some contributions by 2020 due to policy drive by government, to expand access to modern energy and the desire to ameliorate climate change by encouraging the adoption of clean and renewable energy sources. Commercial energy demand will increase by 34.52%, 82.29%, and 139.30% of the base year value of 20.84Mtoe for the reference, high growth and optimistic scenarios respectively.

The base year and projected energy demand by sector are presented in Table 9. Industry, comprising agriculture, construction, mining and manufacturing sector accounted for 4.80Mtoe, representing 14.77%. Transport, household and services sectors accounted for 9.90Mtoe (30.46%), 15.82Mtoe (48.68%), and 1.98Mtoe (6.09%), respectively. By 2020 the industrial sector energy consumption would have overtaken all other sectors, being the driving sector in the development scenarios. The dominance of energy consumption by the household sector instead of the usual situation in developed countries in which industrial sector dominates (EIA/USDOE 2010) is due to the following reasons: i) traditional fuel sources are commonly used in households for cooking and hot water production, with the attendant low efficiency of conversion; ii) the industrial sector is inadequately supplied with energy, hence there is low capacity utilization, that is, the energy demand in the sector is suppressed, especially for electricity, natural gas and fuel oil. The suppression of energy demand is assumed to be gradually removed for all the sectors of the economy and that commercial fuels gradually replace traditional fuel sources. Energy demand of the industrial sector is projected to increase by 38.27%, 78.88% and 87.70% per annum between 2005 and 2020 for the reference, high growth and optimistic scenarios respectively. Over the period 2005-2030, the industrial energy demand is projected to increase by 91.27%, 257.61% and 444.58% of the base year energy consumption in the sector per annum. On the other hand, household energy consumption will increase by 8.72%, 9.84% and 10.90% per annum by 2020 and 13.69%, 15.46% and 16.90% by 2030 for the reference, high growth and optimistic scenarios respectively.

Table 10 shows the electricity consumption in the base year and projections for future years as peak demand. The figure of 5,746MW reported for 2005 represents suppressed demand as only about 55.2% of the entire country was electrified and average household had electricity for only 8hours per day during the year (NBS, 2006). The available capacity should be 8.84, 10.13 and 18.73 times the base year capacity by 2020 and 20.74, 33.41 and 51.84 times the base year capacity in 2030 for the reference, high growth and optimistic scenarios respectively. While generation sources were limited to natural gas and hydro in 2005, the sources of electricity generation would expand to include natural gas, hydro, coal, nuclear, solar and wind in 2020 and 2030 to be able to meet the projected demand for all the scenarios (Sambo, 2008). This is in line with the World Energy Council's position that all energy types need to be given the chance to provide energy in order to achieve the three objectives of sustainable development in the short, medium and long-term perspectives (WEC, 2010).

It can be seen from Table 10 that for Nigeria to be able to have enough electricity that will enable the attainment of the MDGs and Vision 20:2020, it needs to put in place a generation capacity that will meet the demands of between 51,000MW and 110,000MW and its associated transmission and distribution capabilities by 2020. In other words, a minimum generation capacity of between 9000MW and 21000 MW must be put in place within every 3-year plan between 2005 and 2020.

There is no existing study on the Nigeria energy sector, which the results of this study can be readily compared with because of differences in assumptions. The nearest study, which was titled "National Load Demand Forecast, 2008 -2033" assumed GDP growth rates of 6%, 7.5% and 9% per annum for its low, medium and high growth scenarios, respectively (PHCN/World Bank, 2009). The results of the projections showed peak power demand of 9,096MW, 11,701MW and 15,597MW for the low, medium and high growth scenarios respectively by 2020. The study also showed projections of peak power demand of 16,992MW, 26,752MW and 43,939MW for the low, medium and high growth scenarios respectively by 2030. The differences in the underlying assumptions for the two studies are, most likely, responsible for the differences in projected power demand.

Petroleum products are used for driving of vehicles of all types, aircraft, trains and boats within the country and for heating purposes in industry, households and services sectors of the economy. The projected petroleum products demands are shown in Table 11 for the reference and optimistic scenarios. Increase in passenger mobility and transport of goods and services are important consequences of the development aspirations. This will bring about increase in the demand for motor fuels, hence the increasing supply of diesel and premium motor spirit and dual purpose kerosene for air travels. Similarly, demand for LPG will increase due to increasing standard of living brought about by high income levels and desire for cleaner energy fuels. Industries that are running at low capacity presently would run at higher capacities and expanding industrial activities necessitated by demand for goods and services will increase demand for fuel oil which is required for industrial heating purposes. Given that over 80% of current domestic consumption of petroleum products consumption is imported, more domestic refineries need to be established to cater for the domestic demand with less disruption in the supply chain.

The supply of petroleum products in the country has been fairly stable. The projected demand was therefore compared with actual supply in 2005 and 2009 (NNPC, 2005). From Tables 12 and 13, it can be observed that projected demands are generally higher than actual consumption of petroleum products. This observation is most likely due to the fact that the anticipated socio-economic developments in the assumptions for the study are not met in reality. For instance, while it was anticipated that the manufacturing sector will contribute between 7% and 15% to the GDP between 2005 and 2010, the actual contribution averaged 3.98% over the period 2005-2009(NBS, CBN, 2008).

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

The Model for Analysis of Energy Demand to develop an outlook for the energy demand was applied for Nigeria for the period 2005-2030. The results of the energy analysis give the energy implications of the development aspirations of Nigeria and the challenges of supplying the projected energy demand. The structure of energy consumption in the base year demonstrates that current systems of energy supply and use are clearly not sustainable in economic, environmental and social terms, with overdependence on traditional fuels and low modern energy (electricity and petroleum products) consumption and generally low energy and electricity consumption per capita. With more vigorous government action, the trend can be changed to a sustainable path. There should be a strong commitment to increase investment in the provision of adequate modern energy sources in order to power the development aspirations. The aspirations cannot be met with current energy system based mainly on traditional fuels and inadequate and unreliable modern energy (Ojosu et al, 2009). Reliance on importation of motor fuels is not sustainable in the long term. Government needs to create the enabling environment to encourage private sector participation in the establishment and management of refineries in the country.

The energy demand projection study was conducted before the release of the Final Blueprint of the Nigeria Vision 20:2020 (FGN, 2009). Hence, some of the input assumptions for the study are different from the assumptions in the Blueprint. However, except for the projected population, none of the differences in the input parameters may significantly affect the energy demand projections. Although the energy implication of the government's Vision20:2020 is very huge, it is technically feasible to progress towards sustainable supply in meeting the goals. Petroleum products would have to be made available at affordable costs in all parts of the country and efficiency of use improved to discourage the use of traditional fuels. Household access to grid electricity will have to cover the entire country and availability increased to 24hours daily.

## ACKNOWLEDGEMENT

The enormous contribution of the Planning and Economic Studies Unit, Nuclear Energy Department of the International Atomic Energy Agency that provided the Model for the Analysis of Energy Demand (MAED) and the training for the utilization of the Model is highly acknowledged by the Energy Commission of Nigeria.

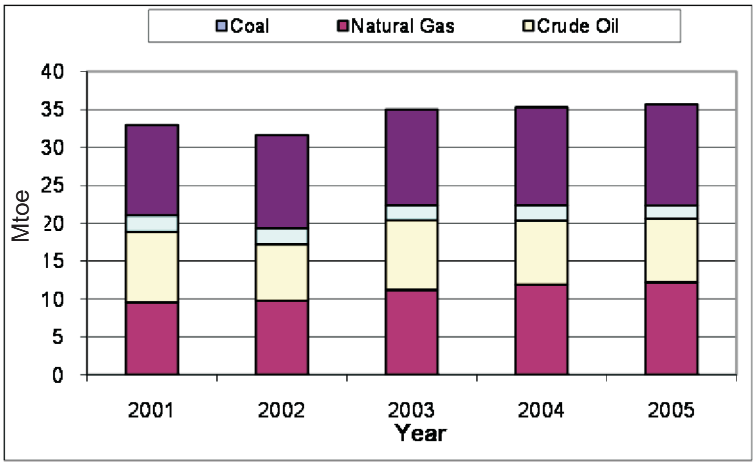


Fig. 1. Consumption of Primary Energy Sources

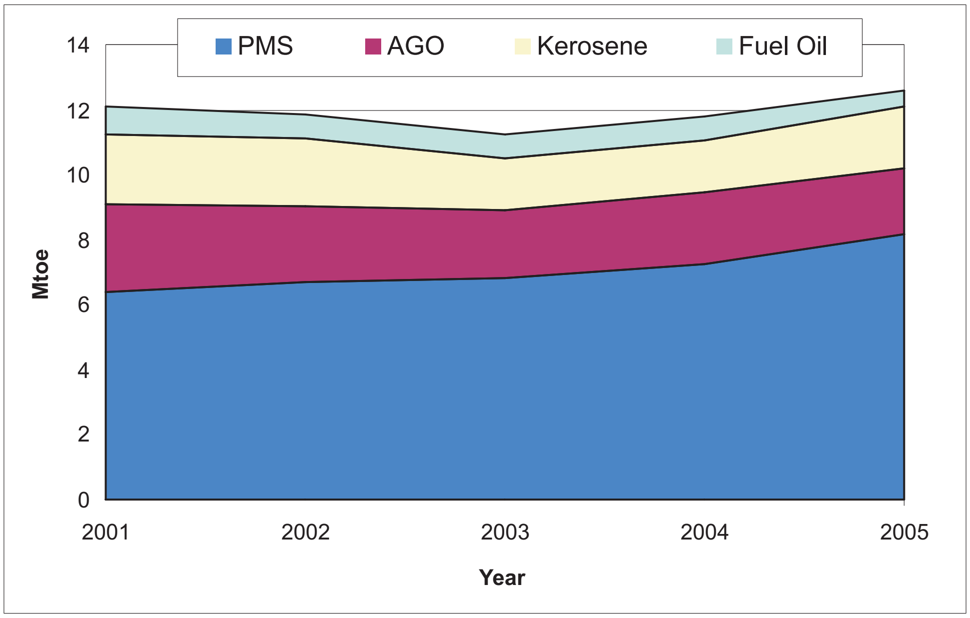


Fig. 2 Consumption of Petroleum Products in Nigeria.

Table 1. Final Energy Consumption in 2005 by Sector and by Energy Form, (000toe)

| Economic Sector | Fossil fuels (thermal use) | Fossil Fuels (transportation) | Coal Coke | Feed stocks | Electricity | Traditional fuels | Total | Percentage of total (%) |
|---|---|---|---|---|---|---|---|---|
| Manufacturing | 774.30 | 0.00 | 40.84 | 278.03 | 989.24 | 8.12 | 2090.53 | 6.43 |
| Agriculture | 0.27 | 9.50 | - | - | 0.67 | 0.00 | 10.44 | 0.03 |
| Construction | 2.07 | 66.15 | - | - | 50.64 | 0.00 | 118.87 | 0.37 |
| Mining | 3.04 | 2.08 | - | - | 1.54 | 0.00 | 6.66 | 0.02 |
| Transportation | 0.00 | 9168.75 | | - | 0.00 | 0.00 | 9168.75 | 28.43 |
| Household | 1520.00 | 0.00 | - | - | 2158.08 | 14794.28 | 18472.36 | 56.86 |
| Services | 49.81 | 0.00 | - | - | 1522.71 | 1046.94 | 2619.46 | 8.06 |
| Total | 2349.49 | 9246.48 | 40.84 | 278.03 | 4722.89 | 15849.34 | 32487.07 | |
| Percentage of total (%) | 6.56 | 28.67 | 0.13 | 0.86 | 14.64 | 49.14 | 100 | |

Table 2: Evolution of the Economy for the Three Scenarios, %

| Sector\Year | 2005 | 2020 | | | 2030 | | |
|---|---|---|---|---|---|---|---|
| | | Reference | High Growth | Optimistic | Reference | High Growth | Optimistic |
| Agriculture | 41.19 | 33.75 | 27.32 | 29.00 | 27.90 | 19.20 | 15.00 |
| Construction | 1.52 | 5.40 | 5.35 | 3.90 | 7.00 | 7.00 | 6.30 |
| Mining | 0.27 | 0.49 | 0.48 | 0.42 | 0.55 | 0.56 | 0.56 |
| Manufacturing | 3.79 | 11.00 | 18.40 | 15.00 | 15.00 | 24.00 | 25.00 |
| Energy | 27.85 | 8.36 | 20.00 | 20.00 | 4.35 | 9.00 | 9.00 |
| Services | 25.38 | 41.00 | 28.45 | 31.68 | 45.20 | 40.24 | 44.14 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table 3: Evolution of the Demographic Parameters for the Three Scenarios

| Year/ Demographic parameter | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Total Population (million) | 137.49 | 163.4 | 196.96 | 239.63 | 291.55 | 352.67 |
| Population Growth rate (%) | 3.16 | 3.52 | 3.80 | 4.00 | 4.00 | 3.88 |
| Urban Population (million) | 55.00 | 75.19 | 96.51 | 127.00 | 166.18 | 211.60 |
| Urban population share (%) | 40 | 46 | 49 | 53 | 57 | 60 |
| Potential labour force (million) | 92.94 | 110.82 | 134.33 | 164.72 | 202.77 | 248.28 |
| Actual labour force (million) | 74.35 | 88.86 | 107.86 | 132.54 | 163.86 | 201.75 |
| Number of persons per household | 5.8 | 5.6 | 5.4 | 5.2 | 5.0 | 4.8 |

Table 4: Development of Freight and Passenger Transportation

| | | | 2020 | | | 2030 | | |
|---|---|---|---|---|---|---|---|---|
| | | 2005 | Reference Scenario | High Growth Scenario | Optimistic Scenario 2 | Reference Scenario | High Growth Scenario | Optimistic Scenario 2 |
| Freight, billion tkm | | 140.88 | 380.25 | 427.38 | 803.28 | 737.66 | 1735.54 | 2793.53 |
| Modal split of freight transportation, % | Truck | 50.56 | 50.56 | 50.56 | 49.25 | 50.56 | 50.56 | 48.88 |
| | Train | 0.01 | 0.12 | 0.12 | 17.40 | 0.3000 | 0.2 | 27.00 |
| | Pipeline | 49.43 | 49.32 | 49.32 | 33.35 | 49.2 | 49.2 | 24.12 |
| Passenger intracity, billion pkm | | 177.72 | 440.39 | 449.66 | 514.56 | 964.48 | 1018.76 | 1273.45 |
| Modal split of passenger intracity transportation, % | Cars | 65.3 | 53.0 | 53 | 53 | 47.3 | 47 | 47.3 |
| | Mass transit | 34.7 | 47 | 47 | 47 | 52.7 | 53 | 52.7 |

Table 5: Development of Energy Consumption in the Household Sector

| | 2005 | 2020 | | | 2030 | | |
|---|---|---|---|---|---|---|---|
| | | Reference Scenario | High Growth Scenario | Optimistic Scenario | Reference Scenario | High Growth Scenario | Optimistic Scenario |
| Electricity penetration | 47 | 80 | 93 | 93 | 95 | 100 | 100 |
| Electricity consumption per household, kWh/dw/yr | 1374.91 | 3940 | 4550 | 5730 | 4400 | 5300 | 6500 |
| Electricity penetration into cooking, % | 3.9 | 5.9 | 7 | 10.3 | 7.0 | 10 | 13 |
| Traditional Energy Penetration into Cooking, % | 72.12 | 52 | 40 | 17 | 12 | 5 | 0 |
| Fossil Penetration into Cooking, % | 23.975 | 42.04 | 52.72 | 71.82 | 80.40 | 83.90 | 84.95 |
| Hot Water per capita, kWh/cap/yr | 66.90 | 90 | 110 | 156 | 177 | 203 | 272 |
| Fossil Fuels (FF) for lighting, kWh/dw/yr | 508.98 | 600 | 600 | 600 | 600 | 0 | 0 |
| Dwellings Using Fossil Fuels (FF) for lighting, % | 78 | 56.6 | 56.6 | 56.6 | 56.6 | 0 | 0 |

Table 6: Development of Energy Consumption in the Services Sector

| | 2005 | 2020 | | | 2030 | | |
|---|---|---|---|---|---|---|---|
| | | Reference Scenario | High Growth Scenario | Optimistic Scenario | Reference Scenario | High Growth Scenario | Optimistic Scenario |
| Floor area /employee, sqm | 16.2 | 16.42 | 16.61 | 17 | 16.55 | 16.8 | 17.2 |
| Electricity requirements of old floor space, kWh/sqm/yr | 22.9 | 38.8 | 44.8 | 56.4 | 45 | 50.4 | 63.5 |
| Electricity requirements of new floor space, kWh/sqm/yr | 24 | 40 | 47.3 | 60 | 49.2 | 55.3 | 70 |
| Cooling requirement, kWh/sqm/yr | 135 | 212 | 237 | 274 | 230 | 260 | 310 |

Table 7: Total Final Energy Demand, Million toe

| | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Reference | 32.50 | 49.92 | 76.45 | 112.67 | 158.95 | 224.54 |
| High Growth | 32.50 | 59.45 | 104.22 | 173.62 | 283.01 | 456.96 |
| Optimistic | 32.50 | 80.00 | 130.00 | 202.74 | 387.52 | 747.27 |

Table 8: Final Energy Demand by Energy Form, Mtoe

| | **2005** | **2020** | | | **2030** | | |
|---|---|---|---|---|---|---|---|
| Sector \ Scenario | | Reference | High Growth | Optimistic | Reference | High Growth | Optimistic |
| Non-commercial | 11.66 | 14.72 | 13.34 | 10.27 | 10.04 | 7.39 | 0.70 |
| Electricity | 5.93 | 31.19 | 50.25 | 60.19 | 67.78 | 129.29 | 196.32 |
| Soft solar | 0.00 | 0.04 | 0.05 | 0.08 | 0.18 | 0.23 | 0.34 |
| Fossil fuels (thermal) | 4.57 | 8.93 | 60.44 | 63.70 | 71.83 | 199.58 | 316.97 |
| Fossil fuels (transportation) | 9.98 | 37.27 | 45.85 | 59.46 | 52.26 | 107.48 | 182.40 |
| Coking Coal | 0.09 | 0.95 | 2.20 | 2.23 | 2.61 | 8.16 | 12.36 |
| Feedstock | 0.27 | 0.47 | 1.48 | 6.81 | 0.84 | 4.83 | 38.18 |
| Total | 32.50 | 112.67 | 173.62 | 202.74 | 224.54 | 456.96 | 747.27 |

Table 9: Final Energy Demand by Economy Sector, Mtoe

| **Sector/Year** | **2005** | **2020** | | | **2030** | | |
|---|---|---|---|---|---|---|---|
| | | Reference | High Growth | Optimistic | Reference | High Growth | Optimistic |
| Industry | 4.80 | 45.92 | 94.66 | 105.24 | 109.52 | 309.13 | 533.49 |
| Transport | 9.90 | 25.82 | 31.88 | 42.29 | 48.54 | 70.70 | 123.37 |
| Household | 15.82 | 34.50 | 38.92 | 43.11 | 54.16 | 61.16 | 66.85 |
| Services | 1.98 | 6.43 | 8.16 | 12.10 | 12.32 | 15.97 | 23.57 |
| Total | 32.50 | 112.67 | 173.62 | 202.74 | 224.54 | 456.96 | 747.27 |

Table 10: Electricity Demand Projection, MW

| Scenario / Year | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | |
|---|---|---|---|---|---|---|---|
| Reference | 5746 | 15,730 | 28,360 | 50,820 | 77,450 | 119,200 | |
| High growth | 5746 | 15,920 | 30,210 | 58,180 | 107,220 | 192,000 | |
| Optimistic | 5746 | 33,250 | 64,200 | 107,600 | 172,900 | 297,900 | |
| | | | | | | | |

Table 11: Petroleum Products Demand Projections

| | | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| Reference Scenario | LPG, thousand tonnes | 15 | 41 | 123 | 332 | 742 | 1319 |
| | PMS, billion litres | 12.28 | 15.07 | 21.22 | 29.83 | 41.91 | 58.83 |
| | DPK, billion litres | 2.60 | 3.29 | 4.11 | 5.29 | 6.93 | 9.23 |
| | AGO, billion litres | 2.69 | 6.04 | 8.52 | 11.99 | 16.88 | 23.72 |
| | Fuel Oil, million litres | 580 | 1,469 | 2,839 | 4,604 | 7,216 | 16,029 |
| Optimistic Scenario | LPG, thousand tonnes | 15 | 81 | 286 | 682 | 1341 | 2312 |
| | PMS, billion litres | 12.28 | 18.23 | 35.88 | 61.09 | 107.55 | 196.96 |
| | DPK, billion litres | 2.60 | 3.78 | 6.45 | 9.95 | 16.43 | 28.83 |
| | AGO, billion litres | 2.69 | 7.31 | 14.43 | 24.61 | 43.38 | 79.51 |
| | Fuel Oil, million litres | 580 | 2,664 | 5,641 | 11,909 | 26,147 | 58,873 |

Table 12: Actual consumption of petroleum products, million litres

| Year\ Petroleum Product | PMS | DPK | AGO | Fuel Oil |
|---|---|---|---|---|
| 2005 | 9,826 | 2,167 | 2,329 | 580 |
| 2009 | 8,544 | 698 | 1,361 | 113 |
| | | | | |

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# Evaluation of the Petroleum Potentials of the Northeastern Nigerian Sedimentary Basins

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## ABSTRACT

Petroleum exploration in the northeastern Nigerian sedimentary basins (the Gongola and Bornu Basins) dates back to 1970's. Although no commercial discovery is made to date, petroleum evaluation of these basins suggests similarity with the contiguous basins of Chad and Niger Republics and Sudan, where commercial oil discovery have been made. Three potential petroleum systems have been identified and could prove very effective in planning future exploration campaigns. The evaluation of the petroleum potentials of these basins also reveals numerous exploration challenges that require effective and dynamic strategies, and new perspectives and exploration concepts away from those applicable to the Niger

## 1.0 INTRODUCTION

The northeastern Nigeria includes two main sedimentary basins: the Upper Benue Trough and the Borno Basin.
The Upper Benue Trough is the northeastern geographical subdivision of the Benue Trough and covers an area extending from the Mutum Biyu-Bashar line in the southwest to the Dumbulwa-Bage high in the northeast as shown in Fig. 1. Most authors see the Upper Benue Trough as made up of two basins: an east – west trending Yola arm (Yola Basin) and north – south trending Gongola arm (Gongola Basin) also shown in Fig. 1. These two basins are separated by a structural high area dissected by four major NE-SW trending sinistral strike-slip faults as shown in Fig. 1 (the Gombe, Bima-Teli, Kaltungo-Wuyo and Shani faults) termed the "Zambuk Ridge" by Carter et al, 1963 or "Wuyo-Kaltungo high" by Zaborski, 1998. The Gongola Basin is controlled by numerous N-S and NNE-SSW trending faults while the Yola Basin appears to have been characterized by E-W trending faults Maurin and Guiraud, (1990).

The Bornu Basin (Chad Basin sector of Nigeria) lies further to the northeast of the Upper Benue Trough. It extends from the "Dumbulwa-Bage high" northeasterly to the Lake Chad and occupies an area of about 23,000km$^2$. Structural trends in the Bornu Basin are generally NE-SW.

The northeastern Nigerian basins are part of a megarift system termed the West and Central Africa Rift System (WCARS). The WCARS includes the Termit Basin of Niger and western Chad, the Bongor, Doba and Doseo Basins of southern Chad, the Salamat Basin of Central African Republic and the Muglad Basin of Sudan as shown in Fig. 2. The WCARS is linked to rifting followed by the opening of the South Atlantic Ocean during the Early Cretaceous and was subsequently modified strongly by transcurrent (strike-slip) faulting at its central axis. Several commercial oil and gas discoveries have been made as shown in at several stratigraphic horizons in Niger, Chad and Sudan sectors of the WCARS, except in the Upper Benue Trough and Bornu Basin.

In this article therefore, evaluation of the petroleum potentials of these basins will include regional synthesis with contiguous basins of Chad and Niger Republics and Sudan. For the Upper Benue Trough, the evaluation will concentrate on the Gongola Basin because of its thick sedimentary succession (up to 6000m) and presence of post-Santonian sediments that played an important role of enhancing maturity and. sub-cropping potential structures generated by the Santonian tectonic inversion. The Yola Basin is relatively of less interest because it lacks the post-Santonian sediments, and the Santonian tectonic structures have been unroofed by erosion as well.

## 2.0 EXPLORATION HISTORY

### 2.1 THE BORNU BASIN

The first permit for hydrocarbon exploration in the Bornu Basin was granted to NAPIMS, a subsidiary of Nigerian National Petroleum Corporation (NNPC), in early 1970's. Exploration started with the acquisition of aeromagnetic and gravity data. In 1977, NAPIMS through IDSL (another subsidiary of NNPC) acquired a total of 13,378.09km of 2-D seismic using thumper energy source, and in 1983 additional 20,266.91km of 2-D seismic was acquired using dynamite technique. Earlier interpretation of generated seismic data was done on a regional scale (map scale of 1:100,000) to provide better understanding of the general basin configuration, major fault trends and general structural and stratigraphic controls in the basin. Later interpretations were on a scale of 1:25,000 for the purpose of identifying specific trends and structural highs considered significant in the evaluation of hydrocarbon reserves. The interpretation of the seismic data identified three tectono-sedimentary sub-basins (areas) (Nwaezeapu, 1992):

(a) Block-faulted and folded area with thick sedimentary cover of up to 10,000m (Avbovbo et al., 1986).
(b) Gentle-slope area associated with listric faulting
(C) Platform area with relatively thin sedimentary pile associated with low relief anticlinal features.

Exploration in the Bornu Basin mainly targeted volcanic plugs wrongly interpreted from seismic lines as anticlinal plays in Fika and top Bima Formation (Nwaezeapu, 1992). Between 1981 to 1997 a total of 23 unsuccessful wells (except two with non-commercial gas quantity) with an average depth of 3,263m were drilled, mainly for these plays. Subsequently NAPIMS demobilized from the basin in 1997. Presently there is a renewed interest on the basin and NNPC engaged the services of a consultant company (Mosunmolu Ltd.) to assess the results and data gathered, thus far. From the last quarter of 2009 to date, NAPIMS contracted IDSL in joint venture with United Geophysical for additional seismic acquisition.

### 2.2 THE UPPER BENUE TROUGH (GONGOLA BASIN)

The first permit for petroleum exploration in the Upper Benue Trough (Gongola Basin) was given to three multinational companies (Shell, Chevron and Elf) in 1992, on a production sharing contract. Geological mapping of acquired acreages and aeromagnetic and gravity data acquisition and interpretation were done in 1995 to 1996. Between 1996 to 1999, a total of 4638.91km 2-D seismic was acquired using both vibroseis and dynamite energy sources. Between 1999 to 2000, the Shell, Chevron and Elf drilled the wells Kolmani River-1, the Nasara-1 and the Kuzari-1 to the total depth (TD) of 2785m, 1905m and 1665m respectively. Only well Kolmani River-1 encountered 43m Net gas sands with estimated reserve of 33BCF. Consequently, the three multinationals relinquished their acreages.

## 3.0 REGIONAL TECTONICS, STRUCTURES AND TRAPS

### 3.1 REGIONAL TECTONICS

The origin of the northeastern Nigerian sedimentary basins (the Gongola and Bornu Basins) and the entire WCARS is attributed to the break-up of Gondwana and the opening of the South Atlantic and the Indian Oceans (Benkhelil and Guiraud, 1980) and reflects an aborted break-up within the African plate as shown in fig. 2. Their location and trends appear to have been directly controlled by the reactivation of pre-existing steeply dipping Pan-African strike-slip lineaments (Maurin and Guiraud, 1990; Bumby and Guiraud, 2005).

Generally, basins within the WCARS are

divided into two subsystems: the NW-SE trending West African rift sub-system (WARS) mostly situated in Niger Republic (e.g. Termit Basin) and the E-W trending Central African rift sub-system (CARS) that includes basins of the southern Chad Republic, Salamat Basin of the Central African Republic and the Sudanese basins. While the WARS basins are characteristically rift basins (half-grabens), the CARS counterparts were strongly affected by strike-slip (transcurent) faulting associated with the Central African Shear Zone (CASZ). In this classification, the Bornu and Gongola Basins of Nigeria are considered part of the WARS, representing southwestern extension of the Termit Basin of Niger into Nigeria. The Gongola Basin, however, was highly affected by transcurrent faulting at different times of its evolutionary history such that it developed strong similarity with the Doba and Bongor Basins of the CARS than it does with the contiguous Bornu Basin of WARS. Therefore, the Gongola Basin may be structurally more complex and is expected to develop structures peculiar to both the WARS and CARS.

The tectonostratigraphic framework of WCARS owns its origin to three major rift phases and two non-rift phases shown in Fig. 3. These are:-

**(a) Pre-Rift Phase**

Prior to the beginning of rifting, the areas underlain by the Gongola and Bornu Basins and other WCARS basins were stable and mostly emergent platforms with no definitive rifting but straddled, from place to place, by thin wedges of continental sediments termed the "pre-rift" (Guiraud et al., 1987; Genik, 1993) as shown in Fig. 3. In the Gongola and Bornu Basins, the pre-rift sediments are referred to as "pre-Bima" deposits and may be as old as Late Jurassic (Guiraud, 1993).

***(b) Lower Cretaceous Rift Phase I***

The WCARS began to open as a rift from Late Jurassic – Early Cretaceous (Avbovbo et al., 1986). By the late Barremian time active rifting ceases and was followed by a regional unconformity especially in the WARS basins shown in Fig. 3. In the Bornu and Gongola Basins this phase of rifting is controlled mainly by NE-SW trending major faults.

A short-lived rifting phase was re-established in the Early Aptian and was followed by a thermotectonic sag stage of basin development which subsequently was closed with yet another regional unconformity at the close of the Early Cretaceous (Albian). In the northeastern Nigerian basins however, the Albian regional unconformity is questionable, except perhaps in the Bornu Basin.

During the Phase I rifting, up to 5000m of subsidence accompanied by the deposition of syntectonic Lower Cretaceous sediments were reported to have taken place (Genik, 1993).

***(c) Upper Cretaceous Rift Phase II***

The rift Phase II began with a short-lived period of late Albian – Cenomanian followed by a long period of thermotectonic subsidence shown Fig. 3 (Genik, 1993) The thermotectonic sagging had the effect of deepening and widening existing sedimentary basins. This corresponded with a general sea level highstand (Haq et al, 1987), and together, these resulted in a widespread marine transgression into the sagged rifts during the Late Cretaceous. In particular, there was marine incursion southwards from the Neotethys through Mali and Algeria and into Niger, and northeastwards from the Gulf of Guinea through Nigeria and into Chad and Niger. This culminated into the merger of the two seas over the Upper Benue Trough of Nigeria (Kogbe, 1972; Petters and Ekweozor, 1982; Reyment and Dingle, 1987; Bumby and Guiraud, 2005).

Regression began due to epeirogenic uplift coupled with a sharp basin modifying NW-SE compressional tectonic pulse termed the "Santonian event" (Guiraud and Bosworth, 1997). This event is believed to be associated with a change in the spreading direction/rate within the Atlantic Ocean (Bumby and Guiraud, 2005) and N-S compression between the African and European plates (Guiraud et al., 1987; Guiraud and Bosworth, 1997). Generally, this compressional event manifests in the form of hiatuses and unconformities shown in Fig. 3, and folding and strike-slip faulting leading to the development of transpressional flower structures within the strata of the WCARS basins. An unconformity related to this event was identified from seismic profiles of the Bornu Basin. Although arguments exist with regards to the presence or absence of the "Santonian event" in the Gongola Basin (Guiraud, 1993; Cratchley and Jones, 1965; Benkhelil, 1988, 1989), growing evidences tend to support its presence. Hiatuses on the pre-Santonian strata especially in the Gombe inlier and consistent discrepancies in beds attitude shown by pre and post-Santonian strata in the Gongola Basin suggest the Santonian compression event.

The "Santonian event" had wide-ranging effects significant for hydrocarbon exploration in the WCARS. It created hydrocarbon trapping folds in southern WARS and CARS (Genik, 1993), folded the northeastern Nigerian Basins (Avbovbo et al., 1986; Benkhelil, 1989), and produced hydrocarbon trapping folds in the Muglad Basin of Sudan (Giedt, 1990).

After the Santonian compression, mild uplift continued until about end Cretaceous (end Maastrichtian) and the rift Phase II was terminated by a regional unconformity brought about by yet another NW-SE terminal Cretaceous compression (Maastrichtian event) (Zaborski, 2000). This event also created additional hydrocarbon trapping structures within the WCARS (including the northeastern Nigerian basins).

During rift Phase II, 3000 – 6000m of subsidence was recorded in Upper Cretaceous marine to continental sediments of the WCARS (Genik, 1993).

***(d) Palaeogene Rift Phase III***

The Palaeogene rifting affected mostly the WARS basins with an estimated rift and thermotectonic subsidence of up to 2000m and 3000m respectively (Genik, 1993). The contained sediments are continental except for a marine sag interval deposited in middle Eocene as shown Fig. 3 (Genik, 1993). In the northeastern Nigerian basins, the deposited sediments were exclusively continental.

In contrast to the WARS, the CARS basins were generally emergent during this phase with recorded subsidence of not more than 200 – 300m in places (Genik, 1993).

By the close of Oligocene, rift Phase III was terminated by a regional unconformity.

***(e) Post-Rift Phase***

This is a non-rift phase associated with subsidence and continental sedimentation in the early Neogene (Miocene – Pliocene). Subsequently, uplift and volcanism followed (Grant et al., 1972; Genik, 1993). Continental sediments of Pliocene - Pleistocene were deposited in the Bornu Basin. In the Gongola Basin however, this phase was marked by uplift and erosion. Miocene to Holocene volcanism also affected the two basins (Grant et al., 1972).

## 4.0 STRUCTURES AND TRAPS

The WARS basins in Niger and Chad including the Bongor and Doba Basins in CARS and the Nigerian Bornu Basin are essentially extensional basins (rifted basins) composed of half-grabens, some of which exhibit reversed structural polarities (Bosworth, 19885; Genik, 1993).

The structural style in these dominantly extensional basins are typically tensional and transpressional. The tensional style is characterized by rotated synthetic fault blocks, antithetic fault blocks, horsts and grabens, compactional anticlines draped over basement horst blocks, and hanging-wall rollover anticlines along normal faults. Several of these structures are traps for hydrocarbons in the Termit Basin. Areal closures in fault structures are commonly $12.14x10^6m^2$ (3000 acres; Genik, 1993). Transpressional structural style is in the form of compressional anticlines whose areal closure range from about $4.05x10^6m^2$ (1000acres) to >$40.47x10^6m^2$ (>10,000 acres). These anticlines can be traps for hydrocarbons in the Termit Basin. They are considered to have originated by sinistral transpression during the mid-Santonian event (Genik, 1993).

In the Bongor and Doba Basins, and the Gongola Basin, these mainly extensional structural styles were strongly modified by strike-slip movements during the Santonian. This resulted into numerous transpressional anticlines which form the best oil-trapping structures in the Doba Basin (Genik, 1993). Their areal closure is commonly <$12.14x10^6m^2$ (<3000acres), but can be as large as $72.84x10^6m^2$ (18,000acres) (Genik, 1993).

The CARS basins, on the other hand, excluding the Bongor and Doba Basins, are dominantly transtensional (Genik, 1993). Structures in these basins are complex depicting mixture of extensional, transtensional and transpressional features. Some of the structures are rotated fault blocks, listric faults with rollover anticlines, compressional anticlines, upthrown blocks and negative and positive flower structures. Faulted compressional anticlines of mainly Santonian age are hydrocarbons traps in the Doseo Basin. Areal closure of these anticlines may reach up to $60.70x10^6m^2$ (15,000acres;) (Genik, 1993).

## 5.0 STRATIGRAPHY

The stratigraphy of the northeastern Nigerian sedimentary basins (the Gongola and Bornu Basins) including the Termit and Muglad Basins of Niger Republic and Sudan is shown on Figure 4.

Borrowing from Zaborski and Abubakar (2010), the sedimentary successions in the northeastern Nigerian basins can be categorized into four major assemblages divided on the basis of sequence boundaries (i.e. the presence of unconformity bounding surfaces). These assemblages from the oldest to the youngest are:

a) Assemblage 1: Pre-Rift and part of Lower Cretaceous Rift Phase I sequence consisting of the "pre-Bima" and lower part of the Bima Formation deposits.
b) Assemblage 2: upper part of the Lower Cretaceous Rift Phase I and the lower part of the Upper Cretaceous Rift Phase II sequence consisting of the middle and upper parts of the Bima Formation, the Yolde Formation and the Pindiga Formation (Kanawa, Deba Fulani/Dumbulwa/Gulani and Fika Members) in the Gongola Basin and the Gongila and Fika Formations in the Bornu Basin.
c) Assemblage 3: upper part of the Upper Cretaceous Rift Phase II sequence consisting of the Gombe Formation.
d) Assemblage 4: Palaeogene Rift Phase III and Post rift sequence consisting of the Kerri-Kerri and Chad Formations

**Assemblage 1**

This assemblage comprises of the Pre-Rift and the lowermost part of the synrift Lower Cretaceous Rift Phase I deposits. The assemblage consists of the so-called "pre-Bima" and the lower part of the Bima Formation sediments. This assemblage generally overlies the crystalline basement in both the Gongola and Bornu Basins with age range of Late Jurassic to Barremian.

The distribution of the "pre-Bima" in the Gongola Basin may be spatially restricted but seems to be ubiquitous in the Bornu Basin where it was described as indicative of continental sedimentation composed of conglomeratic facies of alluvial fans developed at the bases of fault scarps followed by interbedded sandstones and terrigenous mudstones. The interbedded sandstones and mudstones were considered to have accumulated within meandering/braided river channels and as overbank floodplain sediments respectively (Simon Robertson report, 1991).

The lower part of the Bima Formation in the Gongola Basin, on the other hand, is a highly variable unit ranging in thickness from 0 to over 1500m in places (Guiraud, 1990). It represents an active rift stage of basin development with lithofacies distribution strongly controlled by syndepositional tectonics which created a number of fault-bounded sub-basins. Syndepositional faulting seems to control the drainage pattern, making it internal, which developed into lakes at the axial regions of the sub-basins away from the source areas represented by uplifted basement horst blocks (Guiraud, 1990). This resulted into the deposition of coeval sedimentary sequences which started with fanglomeratic alluvial deposits close to the uplifted horsts passing laterally into braided river gravelly arkoses and into shally lacustrine deposits towards the centre of the sub-basins shown in Fig. 5. The lower Bima basal fanglomerates overlain by the lower Bima gravelly arkoses are characterized by 3-4m thick multiple fining upward sequences, each comprising at the base of channel pebbles lag capped by large scale trough crossbedded gravels to coarse grained sandstones grading into massive mottled sandstones as shown in Fig. 6 (Guiraud, 1990). In the Bornu Basin, dependable description of the lower part of the Bima Formation is not available due to the lack of outcrop sections, but it may represents the lower part of the "sand member" of the Bima Formation.

**Assemblage 2**

This assemblage is separated from the Assemblage 1 by a regional unconformity which corresponds to major land leveling phase that took place after the sedimentation and structuration of the lower Bima shown in Fig. 7. (Guiraud, 1990) It ranges from Aptian to Santonian and consists of the middle and upper parts of the Bima Formation of the Lower Cretaceous Rift Phase I, and the Yolde and Pindiga Formations of the Upper Cretaceous Rift Phase II in the Gongola Basin shown in Fig. 4. In the Bornu Basin however, the Yolde Formation may not be present and Gongila Formation is the correlative equivalent of the Pindiga Formation shown in Fig. 4. This assemblage was deposited mainly during a thermotectonic sag stage of basin development shown in Fig. 3, strongly influenced by eustatic transgressive and regressive episodes that ushered in by the Cenomanian age (Zaborski and Abubakar, 2010).

The middle part of the Bima Formation is represented by proximal braided river fining upward units of predominantly trough crossbedded coarse to very coarse grained sandstones composed of usually basal conglomerates with erosive under surfaces indicated in Fig. 6. Individual units are mostly capped with white to purple coloured clays that are thin and often not laterally extensive. Thicknesses of individual units range from 3 to 10m. The middle part of the Bima Formation was assigned Aptian to Albian age (Guiraud, 1990) and marks the transition from the active rifting to thermotectonic sag stage of basin development (Zaborski and Abubakar, 2010).

The upper part of the Bima Formation is composed of uniform fining upward units characterized predominantly by planar crossbedded coarse grained sandstones and thin parallel laminated sandstone units as shown in Fig. 6. Mostly, at the upper part of individual fining upward cycles are relatively thick white to pale-blue to purple coloured clays. The sandstones show commonly soft sediment deformation structures that include convolute bedding, overturned crossbedding and sand volcanoes (Samaila et al., 2006). The upper Bima is probably Albian in age and represent deposition in a distal braided river setting. In the Bornu Basin, the upper Bima is probably of Cenomanian age and may constitute the so-called "shale member" of the Bima Formation shown in Fig. 6.

Generally, the Bima Formation may have a total thickness of ≥3300m and is poorly sorted with degree of sorting showing progressive increase from the lower to the upper Bima. This attests to upward maturation which reflects the upward change from tectonic instability to stable periods of the basins development (Guiraud, 1990).

The Upper Cretaceous Series in the Gongola Basin begins with the Yolde Formation which lies conformably on the Bima Formation. The presence of this formation in the Bornu Basin is controversial, however, growing evidences tend to support that the so-called "Bima shale member" in the Bornu Basin may be the Yolde Formation as shown in Fig. 6. The Yolde Formation earlier interpreted as transitional marine (Carter et al., 1963) represents generally a retrogradational barrier island – lagoon depositional environment (Abubakar, 2006). It is also occasionally deltaic in places (Dike and Maigari, 2009). The base of the formation in the Gongola Basin is defined by the first appearance of marine shale while the top is defined by the disappearance of sandstones and the commencement of limestone-shale successions of the overlying Pindiga Formation (Carter at al., 1963). The formation represents the onset of the major late Cenomanian to Turonian transgression that affected the northeastern Nigerian basins and the entire Benue Trough and large parts of the Saharan region that culminated into the establishment of the transsaharan seaway (Zaborski, 2000). Lithologically, the formation is composed of a mixture of several coarsening and fining upward cycles that mainly involve coarse to medium to fine grained sandstones that are occasionally pebbly with erosive bases, bioturbated clays/shales (0.6-4m thick) with marls and thin limestone association, and interbedded silts/fine – medium grained sandstones/thin carbonaceous silts (Abubakar, 2006). Sedimentary structures of the sandstones are mainly planar crossbeddings, relatively few trough crossbeddings (mainly related to the pebbly coarse grained units) and occasionally herringbone crossbeddings and parallel laminations on the fine grained sandstones (Abubakar, 2006). The sandstones are generally moderately well sorted. The Yolde Formation in the Gongola Basin may reach a thickness of up to 200m or more.

The Pindiga Formation in the Gongola Basin and its lateral equivalent in the Bornu Basin (the Gongila Formation) make up the greater part of the Upper Cretaceous in the northeastern Nigerian basins shown in Fig. 6. The lower part of the Pindiga Formation is composed of interbedded limestone and shale (the Kanawa Member). It is predominantly sandy at the middle part (represented by the laterally equivalent Deba Fulani, Dumbulwa and Gulani Members, but shaly with some thin limestones at its upper part (the Fika Member). In the Bornu Basin, the Fika Member is of formational status (i.e. the Fika Formation).The Kanawa Member is upper Cenomanian to lower Turonian and may have a maximum thickness of up to 100m, the middle Pindiga Formation members are middle Turonian and may individually reach a maximum thickness of 180m and the Fika Member is Turonian to Santonian and may reach a maximum thickness of up to 250m (Zaborski, 2000). The lower parts of the middle members of the Pindiga Formation generally represent deposition in shoreface environments while the upper parts represent perhaps continental depositional setting, related generally to a short term regressive episode in middle Turonian times. These sandy members may be absent within the Pindiga Formation in the Kerri-Kerri Basin suggesting continued marine sedimentation in this part of the Gongola Basin.

The Gongila Formation of the Bornu Basin, on the other hand, is dominantly composed of terrigenous mudstones and argillaceous sandstones with subordinate clean sandstones (Nwaezeapu, 1992). Although the basal Gongila Formation of the Bornu Basin was assigned a Turonian age (Simon-Robertson report, 1991), the pollen (*Gnetaceaepollenites sp*.) upon which the age was deduced is a late Cenomanian index species (Lawal and Moullade, 1986; Abubakar, 2006; Abubakar et al., 2006). This misinterpretation, coupled with the established late Cenomanian age of the basal unit of the laterally equivalent Pindiga Formation in the Gongola Basin, strongly suggest late Cenomanian to Turonian age for the Gongila Formation. The Gongila Formation may reach a maximum thickness of up to 800m (Avbovbo et al., 1986). A thickness of up to

650m has been suggested for the overlying Fika Formation.

**Assemblage 3**

This assemblage is made up of the Gombe Formation and represents the topmost sedimentary unit of the Cretaceous succession in the Gongola Basin as shown in Fig. 4. Its presence in the Bornu Basin is debatable. The Gombe Formation is generally a coarsening upward sequence made up of several coarsening upward cycles. It has been described as "a sequence of estuarine and deltaic" sediments (Carter et al., 1963) as well as "a prograding linear clastic shoreline succession" (Zaborski, 2000). Recent study however, described the formation as typical of a prograding fluvially-dominated marine delta (Abubakar, 2006). The Gombe Formation unconformably overlies the Pindiga Formation and perhaps the Gongila Formation in the Gongola and Bornu Basins respectively. The formation is composed of predominantly silty micaceous shale interbedded with thin silts and minor very fine sandstones at the most basal part and at the base of each coarsening upward cycle as shown in Fig. 6. This forms the "prodelta facies" of Zaborski et al. (1997) and Abubakar (2006). It may reach a thickness of 20m (Abubakar, 2006). The "prodelta facies" transits into distributary mouthbars made up of very fine sandstones that are mostly rippled to parallel laminated and occasionally hummocky cross-stratified. This is capped occasionally by channel-filling planar to trough crossbedded and rippled sandstones interpreted as distributary channel sands. These sandstones constitute the "bedded sandstone facies" of Zaborski et al. (1997). The "bedded sandstone facies" may reach a thickness of 30m in places. Zaborski et al. (1997) reported the presence of a reddish coloured continental fining upward succession of channel-filling sandstones with intraformational conglomerates at the upper part of the Gombe Formation. This constitutes their "red sandstone facies". The Gombe Formation is also characterized by thin lignitic coal seams that could be up to 2m thick in places (Offodile, 1980). The formation is Campanian to Maastrichtian in age.

The Assemblage 3 was subsequently affected by the terminal Cretaceous compressional event (the Maastrichtian event) which uplifted, folded, faulted and deeply dissected all the Cretaceous sequences.

**Assemblage 4**

The Assemblage 4 comprises of sediments and volcanics associated with a renewed rifting at the beginning of Palaeogene (Palaeogene Rift Phase III) and Post Rift tectono-stratigraphic phase. It consists of the Kerri-Kerri and the Chad Formations accompanied by Neogene to Quaternary volcanic activity in the northeastern Nigerian sedimentary basinsas shown in Fig. 4. This assemblage unconformably overlies the Assemblage 3 and seems to be wholly continental in nature as shown Fig. 6.

The Palaeogene Rift Phase III was associated to an E-W extensional activity followed by a thermotectonic subsidence that resulted in the deposition of the grits, sands and kaolinitic clays of the Kerri-Kerri Formation in the western part of the Gongola Basin (Benkhelil, 1988; Zaborski, 2000). The deposition of the Kerri-Kerri Formation in the Bornu Basin was probably restricted to the southwestern portion of the basin. The Kerri-Kerri Formation represents mainly fluvial (braided river) sedimentation. The presence of lacustrine deltaic sediments at its basal part as reported by Adegoke et al. (1986), if any, is difficult to ascertain. The Kerri-Kerri Formation may reach a total thickness of 320m (Adegoke et al., 1986; Dike, 1993). It may be Palaeocene in age from palynologic data (Adegoke et al., 1978).

The Rift Phase III and the accompanying thermotectonic subsidence terminated at the beginning of the Neogene and was followed by the Post Rift Phase related to transtentional movements, minor subsidence and subsequent uplift to the present time (Genik, 1993). This resulted into the deposition of the continental Chad Formation unconformably on mostly the Cretaceous Fika Formation in the Bornu Basin indicated in Fig. 6, except at the southwestern margin of the basin where the Chad Formation overlies perhaps conformably the Kerri-Kerri Formation. No sedimentation was recorded in the Gongola Basin except normal faulting along the western margin of the Kerri-Kerri Basin (Adegoke et al., 1986).

The Chad Formation is Pliocene to Plaeistocene and consists of lacustrine mudstones and fluvial sandstones as shown in Fig. 6. The sandstone dominated intervals can be locally argillaceous, while the terrigenous dominated intervals are in parts arenaceous containing thin beds of sandstone and/or siltstone (Nwaezeapu, 1992). The formation may reach a maximum thickness of up to 800m (Simon-Robertson report, 1991).

Towards the end of the Cenozoic (Miocene), and until Recent times (Plaeistocene), widespread volcanic activities occurred in the southern and central parts of the Bornu Basin (Obaje et al., 2004) and the eastern part of the Gongola Basin. This resulted into the emplacement of several volcanic plugs in the Cretaceous to Cenozoic sedimentary sequences in the northeastern Nigerian sedimentary basins.

## 6.0 PETROLEUM POTENTIALS

The origin of the northeastern Nigerian basins has been shown to be related to rifting. Basin formed as rift and many rifted basins have high geothermal gradients and large traps for hydrocarbons (Avbovbo et al., 1986). Klemme (1980) showed that 35% of rifted basins contain giant oil fields. The discovery of oil in contiguous basins in Niger, Chad and Sudan (basins that share the same tectonostratigraphic history with the northeastern Nigerian basins) and particularly in the Chadian sector, the discovery of the 33BCF of gas in well Kolmani River-1 in the Gongola Basin (Abubakar et al., 2008) and non-commercial gas in two wells of the Bornu Basin (Nwaezeapu, 1992) attest to the presence of petroleum system(s) in the northeastern Nigerian basins. Petroleum system concept describes the genetic relationship between a pod of active source rock and the resulting oil and gas accumulations and encompasses four essential elements of source rock, reservoir rock, seal rock and overburden, and two processes of trap formation and generation-migration-accumulation of petroleum (Magoon and Dow, 1994). Source rocks generate the petroleum, reservoir rocks store it, seal rocks prevent further vertical migration of the petroleum to the surface where it can be lost, and the overburden (thickness of sedimentary pile above the source and the reservoir rocks) provides adequate temperature at the subsurface that will cook the source rocks to maturity so that they can generate and primarily migrate the oil to the reservoir rocks where it can be stored.

As part of the WCARS, it is instructive therefore to evaluate the petroleum potentials of the northeastern Nigerian basins within the context of the identified petroleum systems in the WCARS. In both the Gongola and Bornu Basins, sediments of over 6000m are abound as shown in Fig. 7. This is far more than the minimum overburden thickness of 1000m (Hunt, 1996) required for a basin to be prosperous when all other elements of a petroleum system are present.

## 7.0 PETROLEUM SYSTEMS

Three petroleum systems can be identified in the WCARS basins (Genik, 1993). These systems are related to the three major rift phases that affected the WCARS, hence mostly individually confined within the identified sequence bounded assemblages.

The identified petroleum systems, from oldest stratigraphic levels to the youngest, are:

### *(a) The Lower Cretaceous Petroleum System*

This petroleum system is generally associated with the rift Phase I and the basal part (Cenomanian) of rift Phase II in the WCARS basins. Petroleum accumulations occur in sandstones of Aptian to Cenomanian alluvial/braided/meandering rivers, and coastal marine and lacustrine delta deposits see Table 1.

In the Muglad Basin of Sudan these sandy reservoirs constitute medium – coarse grained sandstones of the upper Albian – Cenomanian Bentiu Formation with porosity of up to 15-27% at depth interval of up to 3595m (Abdalla et al., 1999). In the Doba and Doseo Basins of the Chad Republic, the sandstones are fine to coarse grained, poorly – fairly sorted and sometimes conglomeratic. They were deposited predominantly in alluvial and braided river channels and as deltaic facies associated with lacustrine settings (Genik, 1993). Porosity ranges from 12-24% (ave. 18%) and permeability is 3-25md (ave. 15md) at depth range of 1500-2700m (Genik, 1993). In Termit Basin of Chad and Niger Republics, deltaic to tidal sandstones of Cenomanian Sedigi Formation constitutes the reservoir.

Source rocks of this system are the Lower Cretaceous (pre-Aptian to Albian) lacustrine shales deposited mainly at the axial part of the rift system in dysoxic to anoxic set-up as shown in Tabl1. They are generally rich in total organic carbon (TOC) and are composed of mainly type I (oil-generating) organic matter (OM). In the Muglad Basin, these source rocks constitute the Neocomian – Barremian Sharaf and Abu Gabra Formations consisting of lacustrine shales rich in amorphous kerogen (>80%) with TOC ranges of 1.5-2.3wt% and high values of hydrogen index (HI) of 338-546mgHC/gTOC (Mustapha and Tyson, 2002). This suggests mainly type I OM. These source rocks (e.g. Tefidet, Alaniara and Tegama Formations) in Niger and Chad Republics basins contain TOC that ranges from 1-14wt% with predominantly type I OM (HI >600mgHC/gTOC) derived from fresh water algae and bacteria (Genik, 1993).

Local seal rocks (3-5m thick) exist as interbedded Lower Cretaceous lacustrine shales while regional seals are provided by the Upper Cretaceous fluvial and lacustrine shales in the Muglad Basin (e.g. Aradeiba and Zarga Formations) and predominantly marine shales in Niger and Chad basins.

In the northeastern Nigerian sector of the WCARS, potential Lower Cretaceous Petroleum System includes sediments of the alluvial-braided-lacustrine Bima and the transitional (barrier island – lagoon and deltaic) Yolde Formations in both the Bornu and the Gongola Basins. As earlier mentioned, however, the presence of the Yolde Formation in the Bornu Basin is debatable. I strongly reserved that the Cenomanian marine part of the Bima Formation (Bima Shale Member) (Simon-Robertson report, 1991), which corresponds to the Seismic Sequence 2 (upper part of Bima Formation, shown in Fig. 8 of Avbovbo et al, 1986) is the representative Yolde Formation in the Bornu Basin.

The potential reservoirs are the alluvial fans and braided river channel sandstones, and perhaps lacustrine deltaic ssandstones of the Bima Formation, as well as, the barrier ridges and inlet channel sandstones and the flood and ebb deltas of the barrier island complex of the Yolde Formation. Sandstone thicknesses in the lower and upper Bima Formation are in the range of 3-10m and may be more than 100m where amalgamated. Sandstone thicknesses in the Yolde Formation ranges between 1-10m (Abubakar, 2006). Porosity and permeability data of these potential reservoirs are very scarce. Nwaezeapu, 1992 reported porosity of as low as 3% in the Bima Formation of the Bornu Basin. In the Gongola Basin, however, porosity varied from 5.58-29.22% and permeability is in the range of 10.67-89.27md (Samaila, 2007). The sandstones of Yolde Formation, on the other hand, are generally moderately well sorted and constitute very important aquifer in the Gongola Basin.

Potential source rocks of this system are the interbedded shales of the Bima and Yolde Formations. These shales are fluvial and perhaps lacustrine in the Bima Formation, and marine to lagoonal in the Yolde Formation. Although little is known on the distribution of the lacustrine facies in the Gongola Basin, Allix, 1983 and Guiraud, 1990 reported the presence of some 350m of alternating shales, silty shales, fine to coarse grained sandstones and minor carbonates in the core of Lamurde anticline. Allix, 1983 interpreted this succession as lacustrine-related shales and delta sandstones. Popoff, 1988 interpreted it as part of a regional lacustrine and perilacustrine succession that existed at depth over much areas of the the upper Benue Trough (including the Gongola Basin). Guiraud, 1991, however, regarded the lacustrine facies as strictly local to the Lamurde area. Source rock assessment (Table 2) indicates TOC range of 0.21-2.82wt% and an average of 0.79wt% for the Bima Formation of the Bornu Basin. 65.4% of samples from the studied data are ≥0.5wt% (the minimum threshold of OM quantity required for hydrocarbon generation). The HIs of these samples, however, range from 30-435mgHC/gTOC, shown in Table 2, with an average of 145.4mgHC/gTOC. This indicates the dominance of gas-generating type II OM. The source rock interval with HIs of as high as 435mgHC/gTOC, however, suggest the presence of localized type I (oil-generating) OM which may be related to lacustrine source rocks as reported from the contiguous basins of Sudan, Niger and Chad Republics. These may constitute important potential source rocks where thickly developed and laterally extensive. In the Bima Formation of the Gongola Basin, the TOC ranges from 0.10-0.87wt% with an average of mere 0.25wt% (Table 2). Only 19.0% of the samples from the studied data (excluding samples Nas 53, 54, 55 from the well Nasara-1) show TOC values ≥ 0.5wt%. HIs are equally low ranging from 21-160mgHC/gTOC shown in Table 2, with an average of 63.7mgHC/gTOC. This indicates the dominance of terrestrially derived type III OM capable of generating mainly gas. An exception to this interpretation, however, is the Rock Eval pyrolysis data of the samples Nas53, 54 and 55, representing a depth interval of 60ft (≈ 18m) from 4710ft (≈ 1436m) – 4770ft (≈ 1454m) in the well Nasara-1 drilled by Chevron in the Gongola Basin. At this depth interval, the TOCs and HIs are anomalously very high (52.10-55.20wt% and 564-589mgHC/gTOC respectively. This, coupled with the bimodality of the $S_2$ peak (pyrolysable hydrocarbon yield) of the Rock Eval pyrogram shown Fig. 9, high extract yield indicated in Table 3 and predominance of oil-related macerals (i.e. fluorinite and exsudatinite, in Plate 1 suggest the presence of reservoired migrated oil at the depth interval shown in Fig. 10. Very low extended hopane distribution of ≥ 0.27 (H31R/H30 ratios, indicated in Table 4 indicates that the oil was generated from lacustrine sediments (Abubakar et al., 2008). These sediments may be the lacustrine shales of the Bima Formation not yet penetrated by the well Nasara-1. Therefore, this may also attests to the presence of effective and mature type I (oil-generating) source rock of lacustrine origin at deeper stratigraphic levels in the northeastern Nigerian sedimentary basins. Potential source rocks from the Cenomanian Yolde Formation, on the other hand, show TOC values of 0.22-0.72wt% from the Bornu Basin (Table 2) and 0.10-12.90wt% in the Gongola Basin (Table 2). Up to 87.5% of samples from the Bornu Basin have TOCs ≥ 0.5wt% with an average of 0.60wt% as opposed to 40% from the Gongola Basin but with an average of 1.7wt%. HIs range from 11-113mgHC/gTOC in the Bornu Basin suggesting type III-IV (gas-generating to death) organic matter refere to Table 2. In the Gongola Basin, the HIs range from 26-171mgHC/gTOC with an average of 53.3mgHC/gTOC suggesting the predominance of type III organic matter but with localized presence of oil and gas generating type II organic matter. Generally, the potential source rocks of the Lower Cretaceous Petroleum System in both the Bornu and the Gongola Basins are mature for hydrocarbon generation showing Tmax values that are generally above the minimum threshold of as shown in 435°C Table 2.

Potential seal rocks of this system consist locally of the interbedded fluvial (floodplain) and lacustrine shales in the Bima Formation, and interbedded shallow marine and lagoonal shales in the Yolde Formation. The sealing shales within the Yolde Formation are occasionally laterally extensive and may reach thicknesses of up to 4m. Regional seal constitutes the marine shales of the lower Pindiga Formation in the Gongola Basin and the interbedded shales of the Gongila Formation in the Bornu Basin.

### *(b) The Upper Cretaceous Petroleum System*

This system is restricted to the sediments of the Upper Cretaceous Rift Phase II which encompasses Assemblage 2 (except the Cenomanian Yolde Formation) and Assemblage 3. The formations involved are the Pindiga and Gombe Formations in the Gongola Basin and the Gongila and Fika Formations in the Bornu Basin indicted in Fig. 4.

This petroleum system is poorly developed and perhaps non-existing in the Muglad Basin of Sudan due to its little or none source rock potential. It is however well established in the Termit Basin of Niger and Chad Republics (Genik, 1993). The reservoirs are mainly deltaic – tidal marine clastics (e.g. Sedigi Formation) and fluvial sandstones of Senonian to Maastrichtian age with porosity in the range of 16-25% (ave. 20%) at depth of 2200-3500m and permeability of 35-82md (ave. 52md) at same depth interval (Genik, 1993). These sandstones are of limited thickness and areal extend but may stack up to 60-70m. The Maastrichtian fluvial sandstones may reach up to 400m thick and has porosities of 25-35% (Zanguina et al., 1998). Source rocks are shales of mostly shallow marine to deltaic depositional environment. They are composed of predominantly type III organic matter and have generated oil and gas in the Termit Basin. Average TOCs are in the range of 0.8-1.5wt% (Zanguina et al., 1998). Occasionally the TOCs may reach up to 30wt% (Genik, 1993), perhaps in coaly facies. The seals are the Upper Cretaceous marine shales, some of which are regional.

The potential source rocks of this possible petroleum system in the northeastern Nigerian basins are shales and limestones of the Pindiga, Gongila and Fika Formations, and perhaps the coals of the Gombe Formation shown in Fig. 4. TOCs from available data are in the range of 0.07-3.87wt% (ave. 0.81wt %) with 81.8% of samples ≥ 0.5wt% in the Gongila and Fika Formations of the Bornu Basin indicated in Table 5. HIs from these formations are 10-255mgHC/gTOC with an average of 55.2mgHC/gTOC as indicated in Table 5. This suggests the dominance of terrestrially-derived type III OM capable of generating mainly gas at adequate depth. Available data from the Pindiga Formation indicates 0.10-2.45wt% TOCs (ave. 0.59wt %) with 57.95% of samples having TOCs of ≥ 0.5wt%. HIs are very low (5-180mgHC/gTOC) suggesting poor generating potential, except in the upper part of the formation (Fika Member) where HIs are mostly above 150mgHC/gTOC shown in Table 5. The upper part suggests oil and gas generating type II organic matter. Shale and shaly coal samples of the Maastrichtian deltaic Gombe Formation show TOC ranges of 0.20-23.7wt% with 87.5% ≥0.5wt% as indicated in Table 5. Average TOC is 9.25wt% in the shaly coal facies and 0.79wt% in the shale facies. HIs range from 2-280mgHC/gTOC with an average of 19.17mgHC/gTOC in the shaly facies and 112.75mgHC/gTOC in the shaly coal facies. This suggests that the shaly coal facies are potential source rocks for gas and some oil locally, where HIs are more than 150mgHC/gTOC). The Tmax values of the Gongila and Fika Formations of the Bornu Basin are mostly above the minimum threshold, hence are generally mature and capable of hydrocarbon generation. The Pindiga and Gombe Formations of the Gongola Basin, on the other hand, show immaturity. Most of those areas from which the data in Table 5 is derived come from the less deeply buried parts of the Gongola Basin. In the Kerri-Kerri sub-basin, located in the western Gongola Basin shown in Fig. 1, these formations are overlain by the Kerri-Kerri Formation, hence may have been buried to greater depth to reach hydrocarbon generation maturity.

Possible reservoirs for this system are mainly mid-Turonian sandstones of the middle Pindiga Formation (the Deba Fulani, Dumbulwa and Gulani Members) and the Gombe Formation shown in Figs. 4 and 6. The limestones of the Gongila Formation in the Bornu Basin and the Kanawa Member of the Pindiga Formation in the Gongola Basin may also constitute local reservoirs where individual beds are stacked as in the Ashaka cement quarry (limestones reach thickness of 10m here) and where porosities and permeabilities are diagenetically and mechanically enhanced. Generally, the middle members of the Pindiga Formation include moderately well sorted, loosely cemented and thickly developed trough and planar crossbedded, as well as, hummocky cross-stratified medium to coarse grained sandstones that are occasionally pebbly and graded bedded (Abubakar, 2006). Granulestones are also present. These sandstones show coarsening upward cycles at the base, but are fining upward towards the top. The sandstones represent shoreface and fluvial sedimentation at the lower and upper parts of the members respectively (Abubakar, 2006). These sandstones may extend for over 10km and occur over the entire eastern Gongola Basin. The presence of this members in the sub-cropping part of the western Gongola Basin (Keri-Kerri sub-basin) is possible, but have not been proved. Although porosity and permeability data is lacking, these sandstones constitute excellently reliable aquifers that provide constant supply of a large volume of water needs of the Gombe town from semi-artesian wells at Kwadom. They form also highly productive aquifers in the Kumo area with water yield of 5.80-7.10l/sec. (Dike and Maigari, 2009). These indicate excellent reservoir qualities (high porosity and permeability) for the sandstones. The deltaic Gombe Formation, on the other hand, is made up of thickly developed and fairly extensive distributary mouthbars, and distributary and fluvial channel sandstones. These sandstones are moderately well sorted and mostly very fine grained. Porosity and permeability are likely to be highly variable. However, globally the porosities and permeabilities of deltaic sandstone reservoirs range from 11-35% and 250-8000md respectively (Morse, 1994). In the Bornu Basin, Nwaezeapu (1992) observed porosities of as high as 23% for the Gongila Formation.

The shales of the Fika Member could form effective seals for the reservoirs of the middle part of the Pindiga Formation shown in Fig. 4, and 6. The potential reservoirs in the Gombe Formation may be sealed by the intercalating silty shales of the formation, but may not be competently and laterally very effective. Fika Formation is the regional seal for the Upper Cretaceous system in the Bornu Basin.

### *(c) Palaeogene Petroleum System*

This system is best developed in the Termit Basin of Niger Republic and is related to the Palaeogene Rift Phase III. There is little known on this system. The principal source rocks are lower Eocene shallow marine to paralic shales (200-500m thick) and the middle Eocene lacustrine shales (Genik, 1993). The lacustrine source rocks are of high quality type I organic matter, derived from fresh water algae and bacteria, and have generated and expelled mainly oil into middle to upper Eocene fluvial channels and lacustrine delta sandstones, as well as, "laterally" into fluvial sandstones of the Palaeocene shown in Table 1. (Genik, 1993) Oligocene lacustrine shales of up to 1000m thick provide regional seal while interbedded shales of the Eocene provide local seal potential (Genik, 1993).

This potential petroleum system may be absent in the Gongola Basin. In this basin, sedimentation ceased with the deposition of the Palaeocene continental Kerri-Kerri Formation followed subsequently by the Neogene to Quaternary volcanism shown in Fig. 4. The Kerri-Kerri Formation has, however, served to bury potential source rocks in the western Gongola Basin to greater depths than elsewhere and therefore has some relevance in terms of enhancing thermal maturity of the sub-cropping Cretaceous sediments (Zaborski and Abubakar, 2010).

In the Bornu Basin, however, potentials on the presence of the Palaeogene Petroleum System may exist. Here extensive deposition of the Eocene to Pleistocene fluvial – lacustrine Chad Formation on the Palaeocene continental Kerri-Kerri Formation took place as shown in Fig. 4. The Cretaceous Fika Formation may also act as a principal source rock for the system. Constraints to this system, however, may be in fundamentally inadequate thermal maturity of potential source rocks due to shallow levels of burial and perhaps absence of regional seals. Reservoirs at shallow depth levels may also be affected by meteoric water, hence becoming degraded.

## 8.0 HYDROCARBON TRAPS

Traps for hydrocarbons in the northeastern Nigerian basins are expected to mimic those identified in the WCARS basins of Termit, Doba, Doseo and Muglad. The position of the northeastern Nigerian basins at the confluence zone between the predominantly extensional WARS basins (e.g. Termit Basin, etc) and the predominantly transtensional CARS basins (e.g. Doseo Basin) shown in Fig. 2, suggests the possibility of mixed traps peculiar to both the WARS and CARS basins in the Nigerian sector. The fact that the northeastern Nigerian basins share the same tectonic origin and evolution of initial rifting, thermotectonic sagging, strike-slip faulting, and particularly mid-Santonian and end Cretaceous compressive phases with the other WCARS basins, also suggest that the structural traps may be of comparable volumes with those in the Termit, Doba, Doseo, etc. Rapid facies changes characterized the stratigraphic successions of the Bornu and Gongola Basins and this suggests the possibility of the presence of also stratigraphic traps.

Avbovbo et al, 1986 identified the existence of traps within horsts, in the drape or compaction structures over horsts, along normal faults, and along the flanks of horsts in the Bornu Basin of which Genik (1993) asserted are similar to those in the WCARS. Similar structures of E-W trending horsts and grabens related to tensional movements and controlled by synrift N60$^{o}$E trending fault system (generally parallel to sub-parallel to the length of the basin) have been reported from the upper Aptian and older sedimentary successions in the Gongola Basin (Popoff et al., 1983). In the Termit and Bornu Basins shown in Fig. 11, however, this pattern is superposed by NNW-SSE trending antithetic faults linked to latest Cenozoic movements (Genik, 1993). The NNW-SSE trends are also present in the Gongola Basin shown in Fig. 12.

These types of traps are expected to be dominant in the Lower Cretaceous Petroleum System of both the Bornu and the Gongola Basins. The block faulting that produced the horst and graben structures can also provide good migration pathways for generated hydrocarbons (Obaje et al., 2004).

The mid-Santonian and late Maastrichtian compressional events in the basins produced additional fracturing and folding that formed traps associated with large compressional anticlines with four-way dip or fault-assisted closures, and listric faults associated with flower structures (Nwaezeapu, 1992). These traps may be much prevalent in the Upper Cretaceous Petroleum System and are found to dominate the deeper central parts of the basins (Avbovbo et al., 1986, Fig. 13). The faults seem to die out at the end Maastrichtian unconformity that separates the Cretaceous from the Palaeogene sequences indicated in Fig. 14.

Stratigraphic traps may be in the form of onlap and truncational unconformities, buried channels and to a lesser extend pinchouts. The stratigraphic traps may be the dominant types in the Potential Palaeogene Petroleum System of the Bornu Basin. Structural traps will be scarce due to tectonic quiescence that accompany the deposition of the Palaeogene to Quaternary successions in the basin.

## 9.0 PETROLEUM GENERATION

Petroleum generation, its timing and expulsion in the Bornu and the Gongola Basins of the northeastern Nigeria are not known at present. Geothermal gradients, however, is in the range of 2.16-5.26$^{o}$C/100m in the Bornu Basin (Nwaezeapu, 1992) with the highest values in the region of the Neogene to Quaternary intrusive rocks which generally dominate shallow part (flanks) of the basin (Avbovbo et al., 1986). These geothermal gradient values compare well with values of 2.6-2.9°C/100m in the Muglad Basin of Sudan (Abdalla et al., 1999) and 2.5-3.0°C/100m in the basins of Chad and Niger Republics (Genik, 1993). Modeling for hydrocarbon generation in the Muglad Basin and the basins of Chad and Niger Republics using these geothermal gradients, suggests that presently oil-generation window lies at 2,300-5,000m depth in the Niger and Chad Republics basins (Genik, 1993), and at 3,500-4,000m in the Muglad Basin (Abdalla et al., 1999). Zanguina et al, 1998 indicated also that the top of "oil window" in east Niger grabens (e.g. the Termit Basin) is located at a depth of between 2,200 and 2,900m, and that the top of the "gas window" is between 3,600 and 4,000m. These geothermal gradient values and oil-generation windows could be extrapolated for the northeastern Nigerian basins. The most prospective areas may occur in the Central part of the basins where thicknesses of sedimentary cover are high. This constitutes the Kerri-Kerri sub-basin of the Gongola Basin shown in Fig. 1, 7 and central parts of the Maiduguri and Lake Chad sub-basins of the Bornu Basin shown Fig. 7.

It is worth mentioning at this point, the effect of the end Cretaceous (end Maastrichtian) tectonic event and the Neogene to Quaternary volcanism vis-à-vis petroleum generation and preservation in the basins. The effect of the end Cretaceous event may be positive by enhancing trapping mechanisms if petroleum generation post-date it and may be negative, on the other hand, if generation pre-date it. The later may open up some of the earlier formed petroleum traps resulting into tertiary migration of the petroleum to high level traps or loss to the surface. The volcanism has also similar effect depending on whether generation occurs pre- or post-volcanism. If volcanism is pre-generation, it may enhance source rock maturity due to increase in geothermal gradient in adjacent areas, but otherwise it may burn up hydrocarbon accumulations that occur close to the volcanic plutons and sills.

## 10. EXPLORATION CHALLENGES

Exploration challenges in the northeastern Nigerian basins (the Bornu and Gongola Basins) are numerous but fundamentally they include:

(a) Wrong interpretation of seismic data: Analysis showed that 19 out of the 23 wells in the Bornu Basin were drilled off structure and targeted highly reflective "bright spots" (e.g. Wade-1, Albarka-1, etc; sown in Fig. 15 commonly used in the Niger Delta for hydrocarbon detection (Nwaezeapu, 1992). It is now understood that these imbricate-shape amplitude anomalies in the Bornu Basin are manifestations of volcanic plugs and sills embedded in the host rock rather than hydrocarbon presence as occur in the Niger Delta (Nwaezeapu, 1992). The remaining 4 wells targeted thick "reservoir sands" proximal to the identified structure building faults. Such proximal clastics often lack source and seal rocks in half-graben basins like the Bornu and the Gongola. Many discontinuous, low amplitude seismic reflections seen on some seismic profiles from the Bornu Basin, on the other hand, also posed serious interpretation problems (Nwaezeapu, 1992). These were given different interpretations ranging from massive clastics to homogenous limestone beds or shales. Consequent to these wrong interpretations, dry wells were drilled.

(b) Inadequate 2-D seismic density: Exploration in the Bornu and Gongola Basins, so far, utilized 2-D seismic. Structural resolution, using this method, requires shooting numerous seismic lines at relatively short intervals. The 2-D seismic density is grossly inadequate in the northeastern Nigerian basins when compared to what obtains in adjacent Termit Basin where hydrocarbons are discovered as shown in Fig. 16.

(c) Lack of proper grasps of the geology, stratigraphy, structure and architecture of the basins: The Bornu and Gongola Basins, unlike the Niger Delta, are rifted basins with mostly dissimilar structure and architecture, hence require new perspectives and exploration concepts away from that of the Niger Delta.

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(d) Over dependence on the prolificity of the Niger Delta: At the present production rate, the reserve of oil in the Niger Delta will last for decades. Therefore at the moment, multinational companies are not eager to make new discoveries in the Bornu and Gongola Basins, especially since additional production cost over that of the Niger Delta will be involved in the construction of long pipelines and flow stations to the sea for onward transportation to world markets.

## 11.0 FUTURE EFFECTIVE AND SUSTAINABLE EXPLORATION STRATEGIES

In view of the above challenges, it has become obvious that exploration in frontier basins like the Bornu and Gongola Basins will require effective and dynamic strategy and incentives to sustain efforts and make discoveries. From the technical (geologic) perspective, future strategies should include:

(a) Detail and proper understanding of the stratigraphy of the basins through detail geological and structural mapping preferably on a scale of 1:12500, incorporating GIS, radar imageries and aeromagnetic/gravity structural maps, and detail outcrop sections (composite and stratigraphic) and boreholes logs.

(b) Organic facies study employing the conventional elemental typing and bulk compositional study of first formed petroleum. Bulk compositional study is presently the best approach to organic facies characterization (di Primio and Horsfield, 2006), especially where phase, volume and kinetic modeling need to be performed without access to calibration data (this is normally the case in frontier basins like the Bornu and Gongola). It is the most useful research tool for understanding the processes of individual hydrocarbon generation and migration.

(c) Correlation study of the drilled wells with outcrop sections using lithology (lithofacies, potential source and reservoir rocks horizons), palaeontology (preferably palynology), radiometry in some favourable cases and organic facies.

(d) Integration of sequence stratigraphic ideas in petroleum system elements (source, reservoir and seal rocks only) appraisal.

(e) Shallow boreholes drilling at identified localities to test for possible lacustrine shales in the basins (the Gongola Basin in particular because of its good exposures of the Cretaceous formations).

(f) Basinal modeling for depth to hydrocarbon generation window and timing of generation vis-à-vis traps formation.

(g) Risk factor analysis and the development of risk segment maps.

## 12.0 SUMMARY AND CONCLUSION

Three potential petroleum systems may be abounding in the northeastern Nigerian sedimentary basins (the Bornu and the Gongola Basins). These petroleum systems are:

(a) The Lower Cretaceous Petroleum System related to the Pre-Rift and Lower Cretaceous Rift Phase I (including the Cenomanian of the Upper Cretaceous Rift Phase II) tectonostratigraphic sequences. This system may be characterized by mainly good quality (type I organic matter) lacustrine source rocks with high TOCs and adequate maturity. Reservoir rocks are alluvial-braided-lacustrine delta sandstones of Aptian to Albian Bima Formation, and the sandstones of the barrier-island complex of the Cenomanian Yolde Formation. Regional seal could be the shales of the Kanawa Member of the Pindiga Formation in the Gongola Basin and the interbedded shales of the Gongila Formation in the Bornu Basin. This perhaps could be the most promising petroleum system in the basins.

(b) The Upper Cretaceous Petroleum System restricted to the Upper Cretaceous Rift Phase II tectonostratigraphic sequences. The source rocks are marine composed of mostly type III terrestrially derived OM that is marginally mature to immature in the exposed Cretaceous rocks of the eastern Gongola Basin. These source rocks may be mature in the Kerri-Kerri sub-basin where they are buried by the Palaeocene Kerri-Kerri Formation. Good to excellent quality reservoirs are the sandy members of the Pindiga Formation and the sandstones of the deltaic Gombe Formation in the Gongola Basin. Limestones of the lower Pindiga Formation (the Kanawa Member) may form reservoirs where thickly developed and its porosities improved by diagenesis and fracturing. In the Bornu Basin, the reservoirs are mainly the sandstones of the Gongila Formation. Seals are the interbedded shales of the Gongila Formation and Fika Formation in the Bornu Basin, as well as, the shales of the Pindiga Formation in the Gongola Basin. Silty shales of the Gombe Formation may not be very effective.

Structures and traps in the northeastern Nigerian basins mimic those associated with the other basins of the WCARS where petroleum has been discovered.
Data on petroleum generation and timing is not available, but seem to be similar to what obtains in the Muglad Basin of Sudan and the Termit Basin of Niger/Chad Republics. In this basins, present-day depth to petroleum generation-window lies between 3,500-4,000m and 2,300-5,000m respectively.

Exploration challenges are very numerous and require new perspectives and exploration concepts if success is to be achieved.

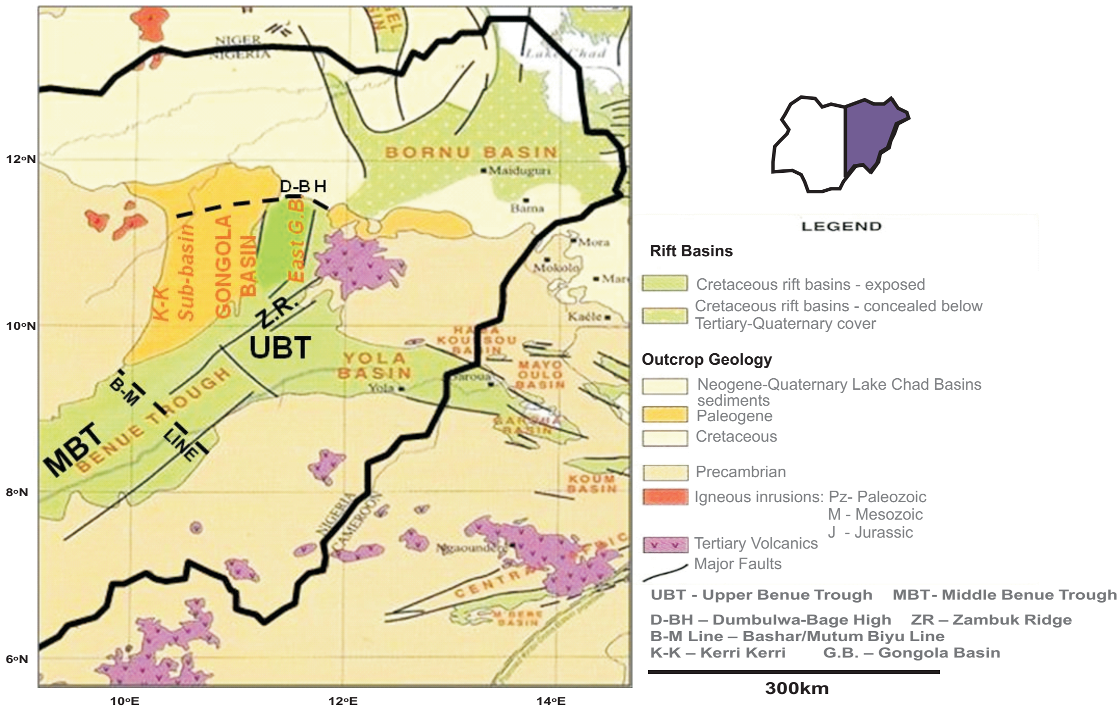



**Fig. 1: Generalized Geology of the northeastern Nigerian sedimentary basins showing Gongola and Bornu Basins.**

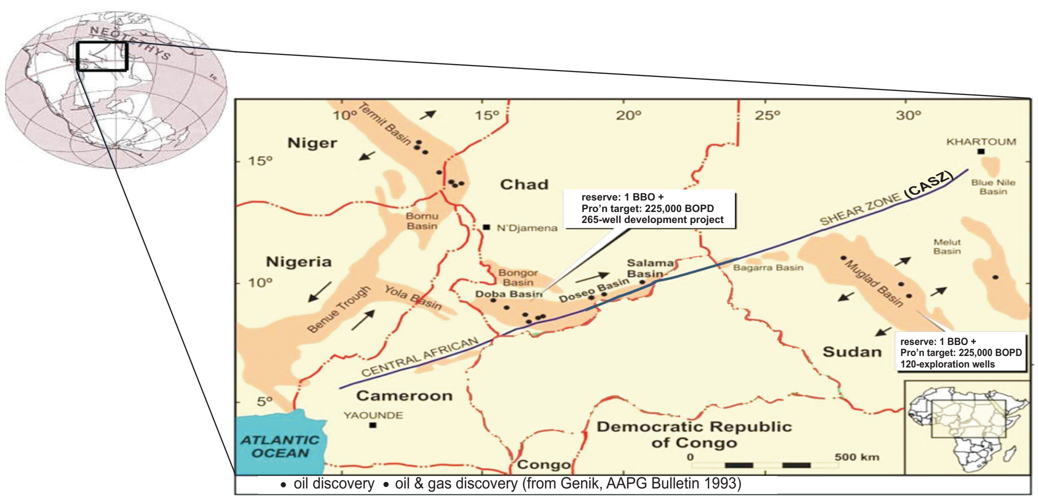



**Fig. 2: West and Central African Rift System showing the locations of oil and gas discoveries (from United Reef Limited Report, 2004).**

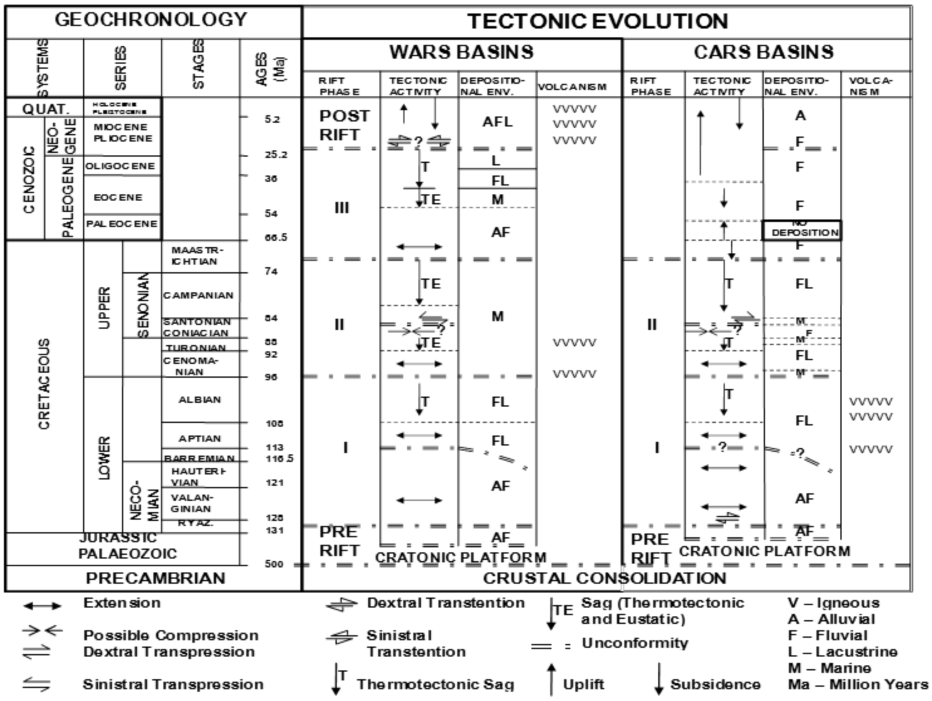


Fig. 3: Tectonic Framework of the WCARS basins (including the Gongola and Bornu Basins) (modified from Genik, 1993).

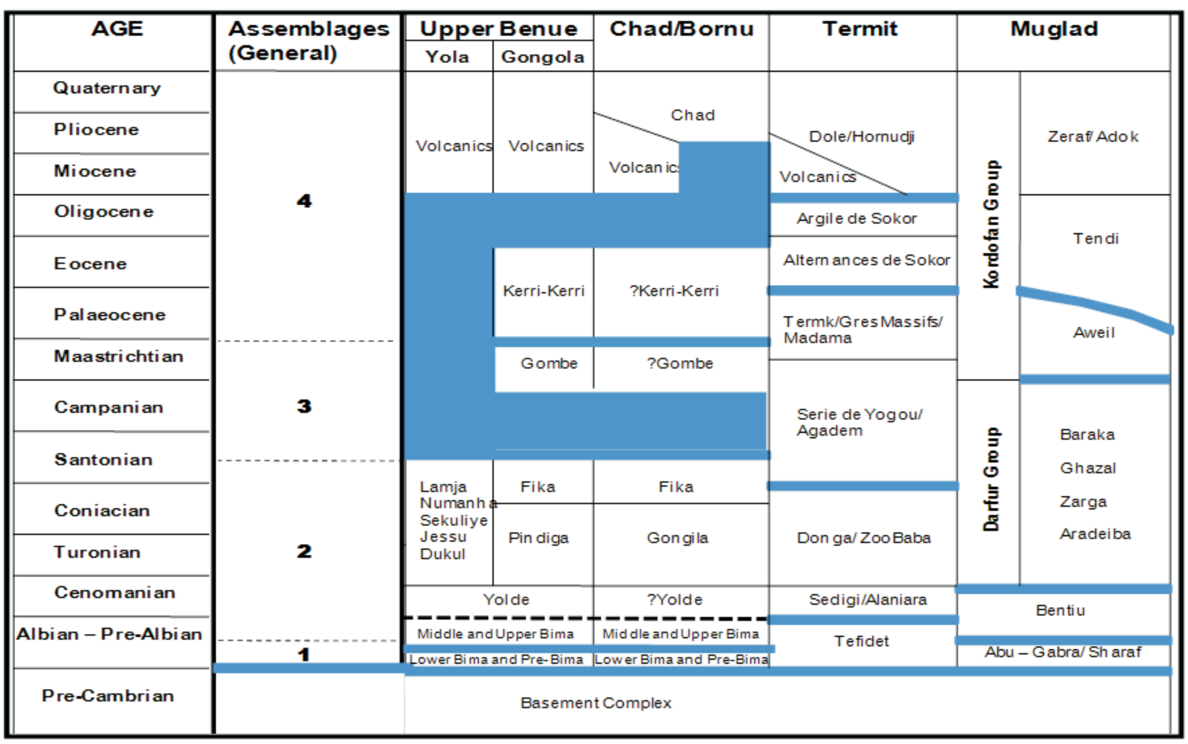


Fig. 4: Generalized stratigraphic successions in the Upper Benue Trough, Bornu, Termit and Muglad Basin.

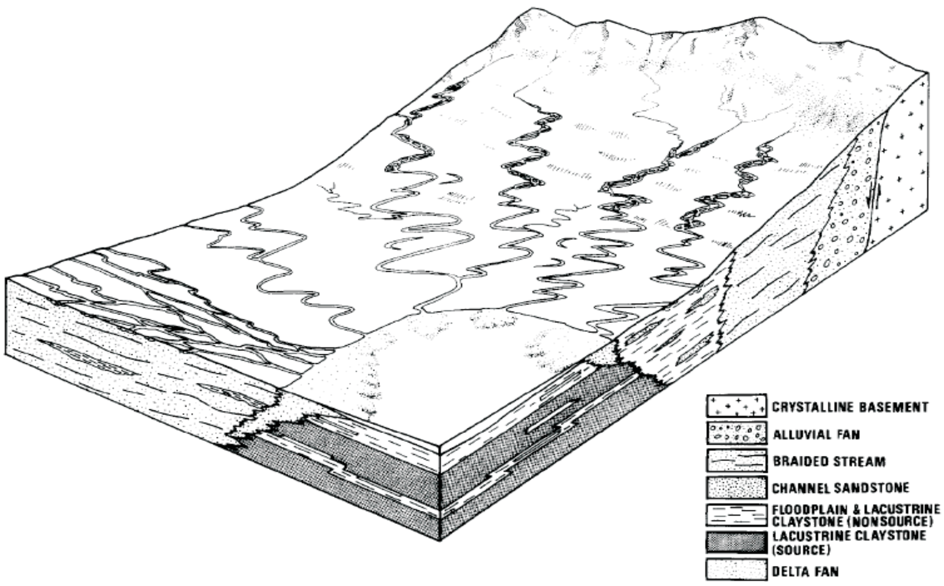



**Fig. 5: Generalized depositional model of the lower part of the Bima Formation (adapted from Schull,1988).**

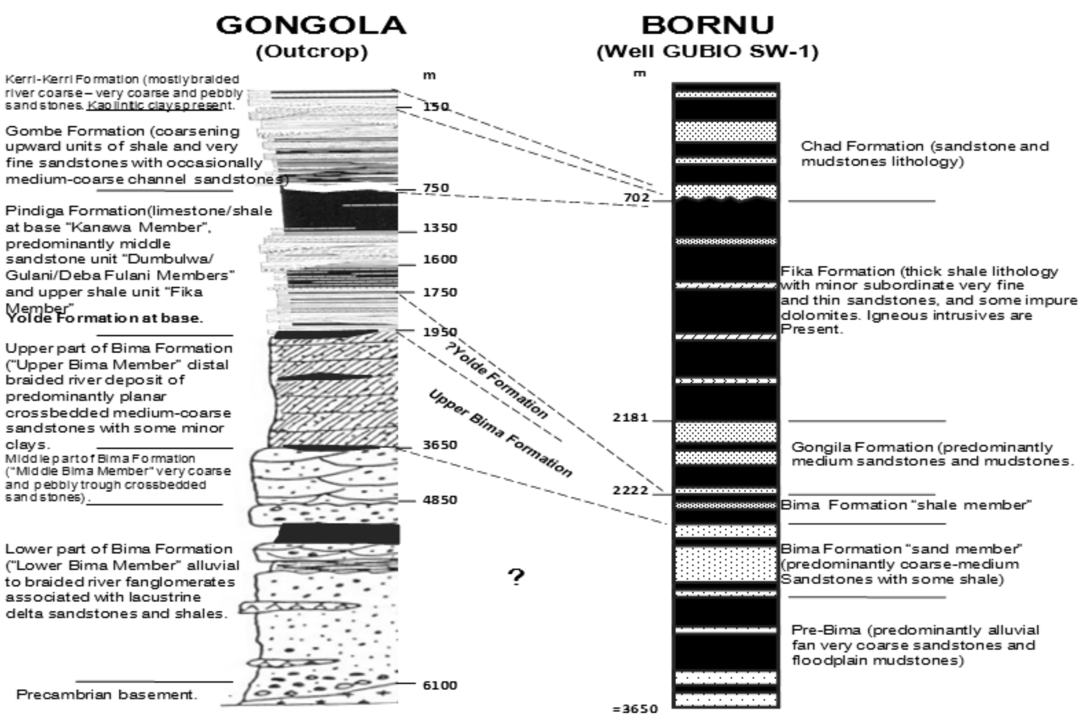



**Fig. 6: Composite stratigraphic sections of the Gongola and Bornu Basins showing correlations (Gongola section modified from Zaborski, 2003 and Rebelle, 1990).**

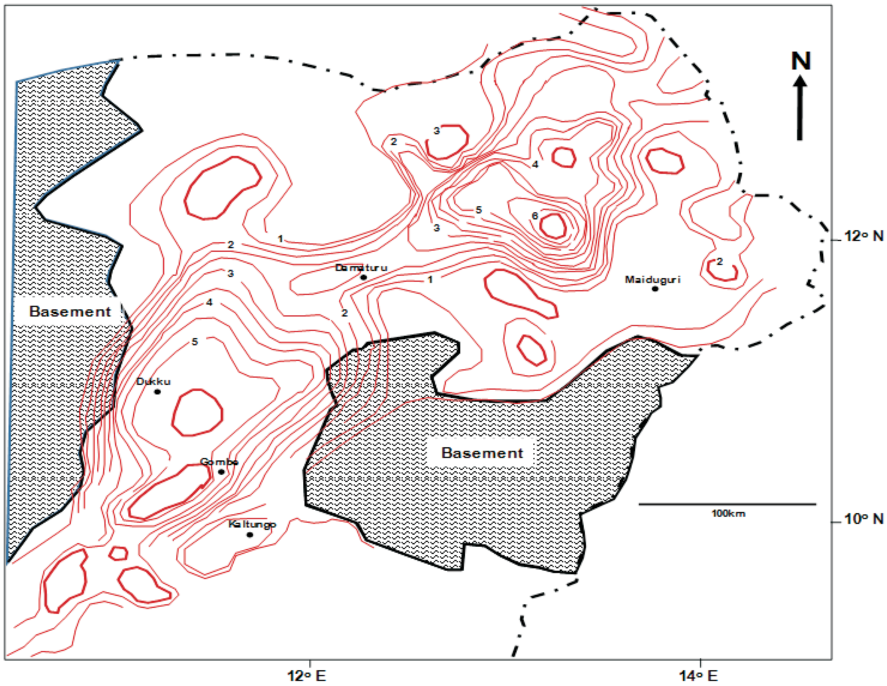



**Fig. 7: Isobath map (contours in Km below sea level) in the Gongola and Bornu Basins deduced from magnetic data (modified from Benkhelil et al.,1989).**

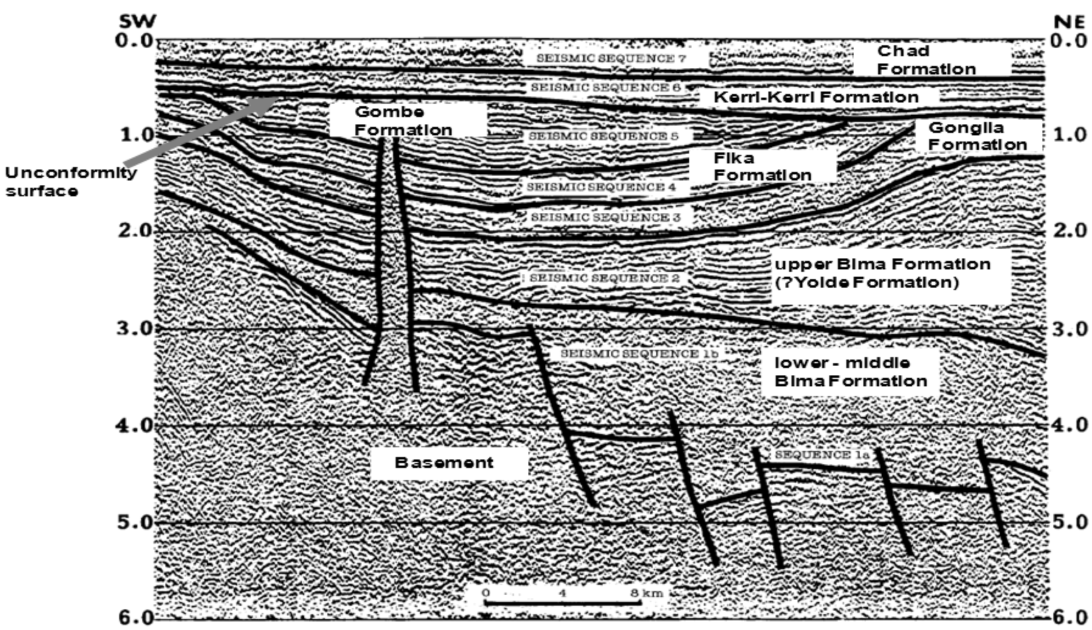



**Fig. 8: Typical seismic section showing various stratigraphic intervals in Bornu Basin. Note the unconformity beneath the Kerri-Kerri Formation (from Avbovbo et al., 1986).**

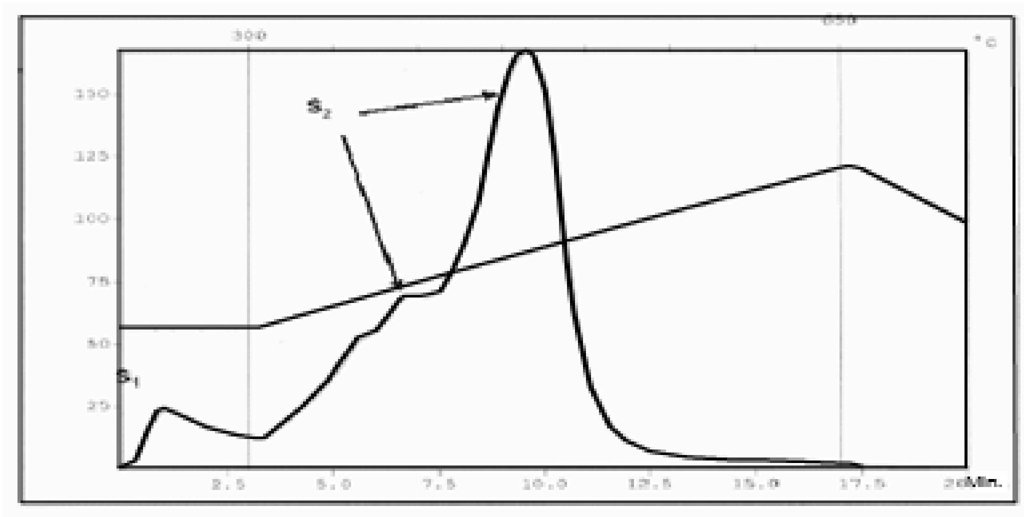



Fig. 9: A pyrogram of sample NAS 53 showing bimodal $S_2$ peak

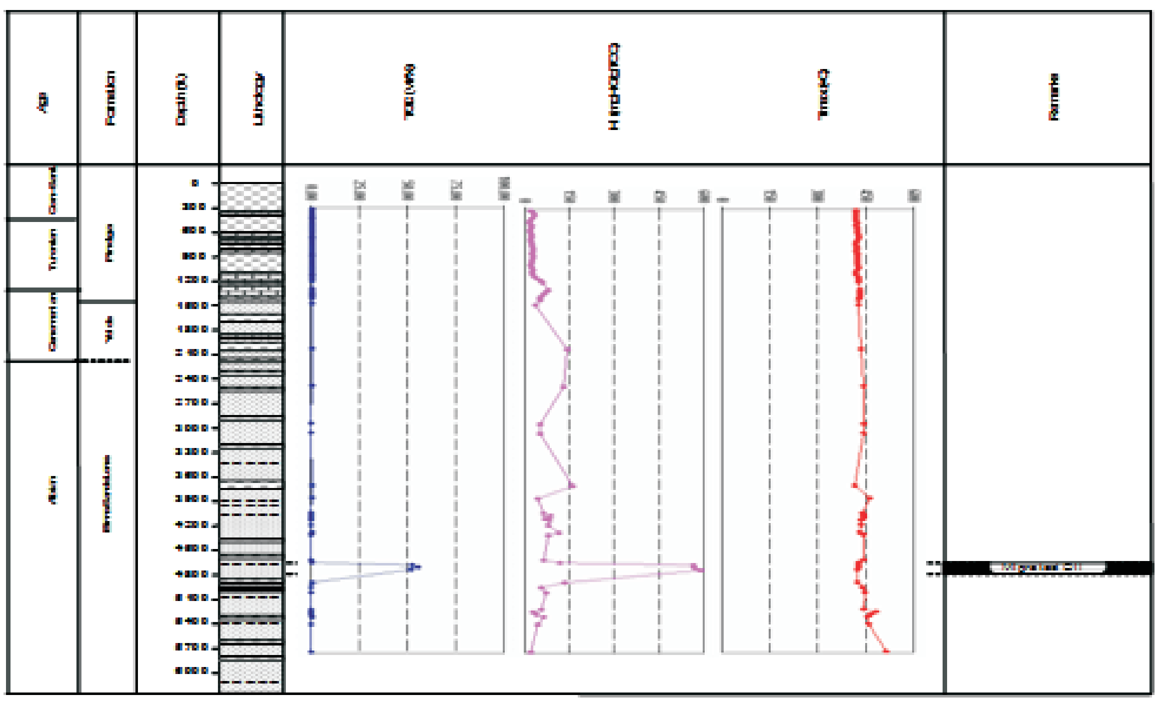


Fig. 10: The stratigraphy of the well Nasara-1 showing TOC, HI and Tmax variation with depth and the interval of possible migrated oil.

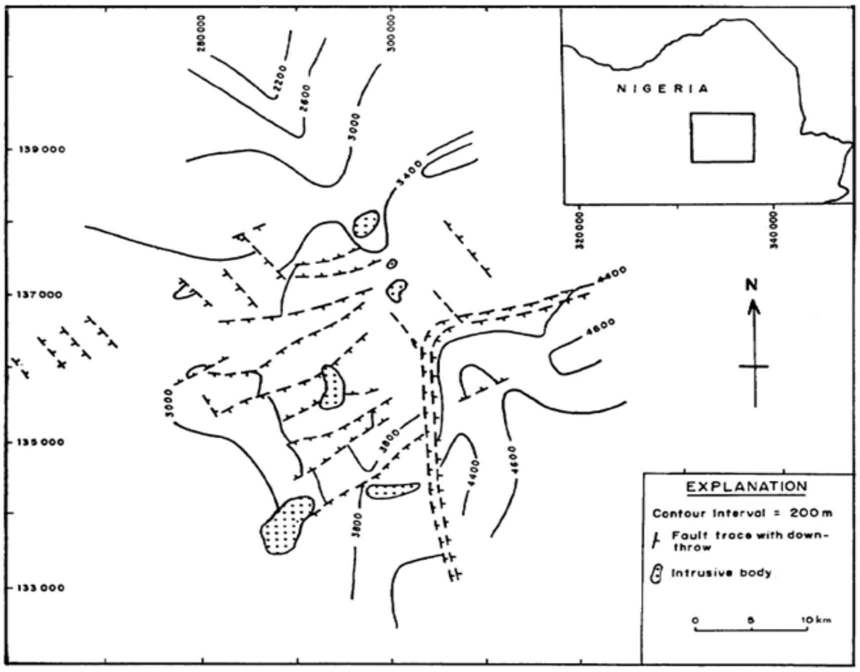



**Fig. 11: Major NE-SW and associated NNW-SSE structural trends in the Bornu Basin (from Avbovbo et al., 1986).**

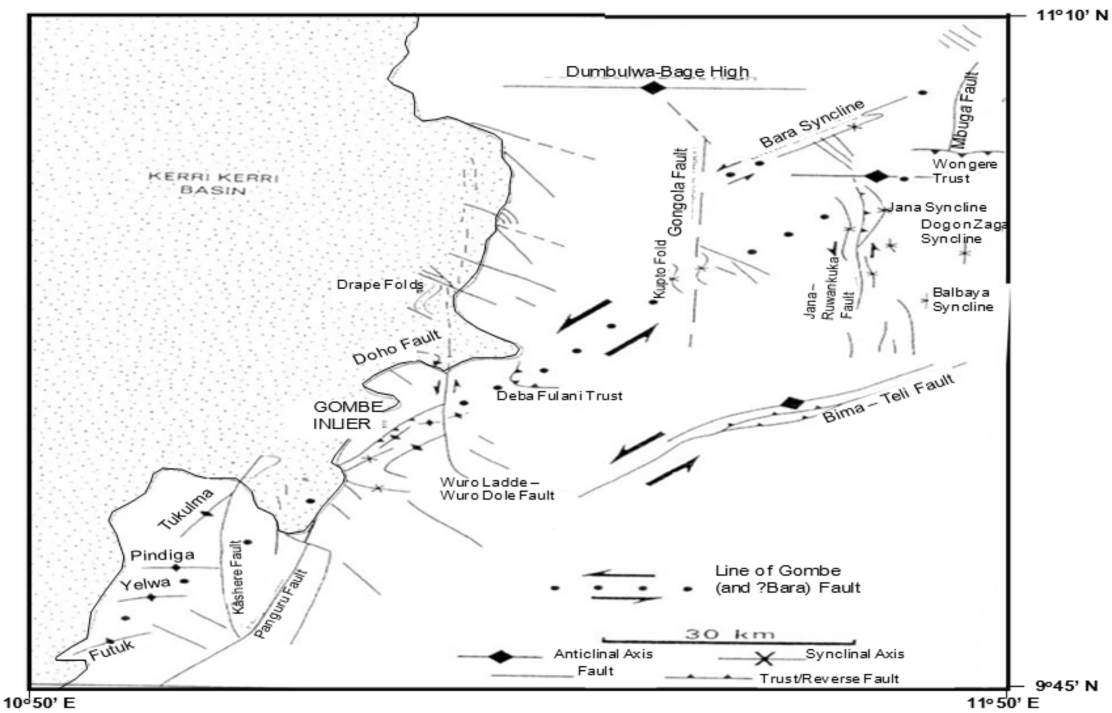



**Fig. 12: Major NE-SW and associated NNW-SSE structural trends in the Gongola Basin (from Zaborski, 1998)**

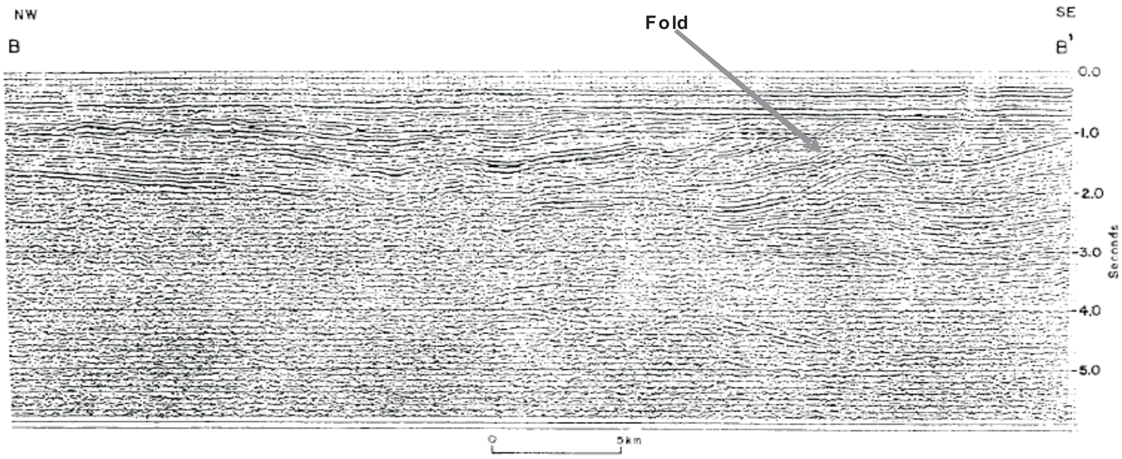
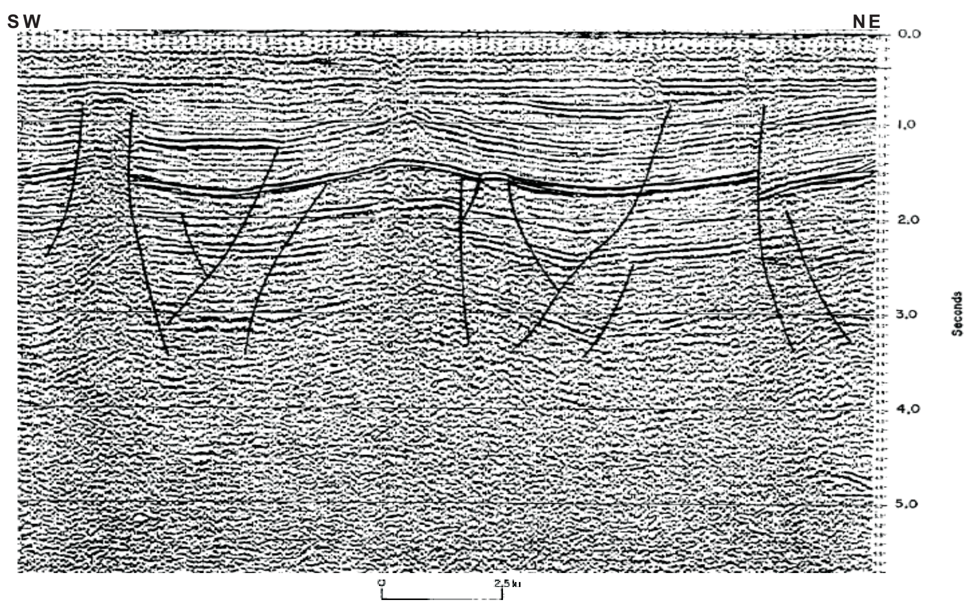



**Fig. 13: Seismic section from the Bornu Basin showing amplitude of folds increasing basinward (towards the central part) (from Avbovbo et al., 1986).**



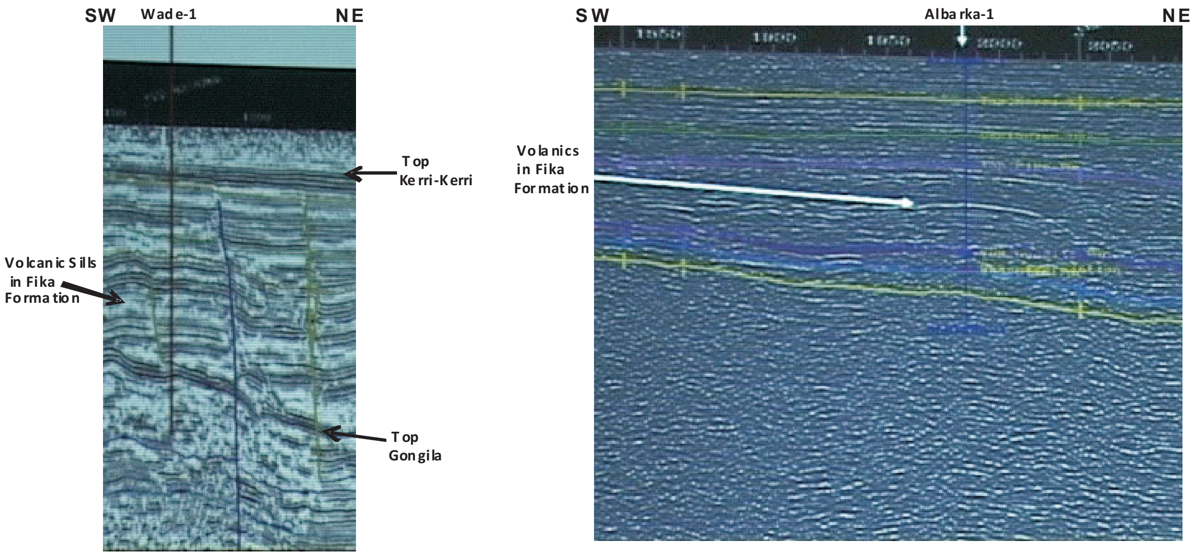



**Fig. 15: Seismic sections from Bornu Basin showing wells targetting "Bright Spots" related to volcanic plugs and sills.**

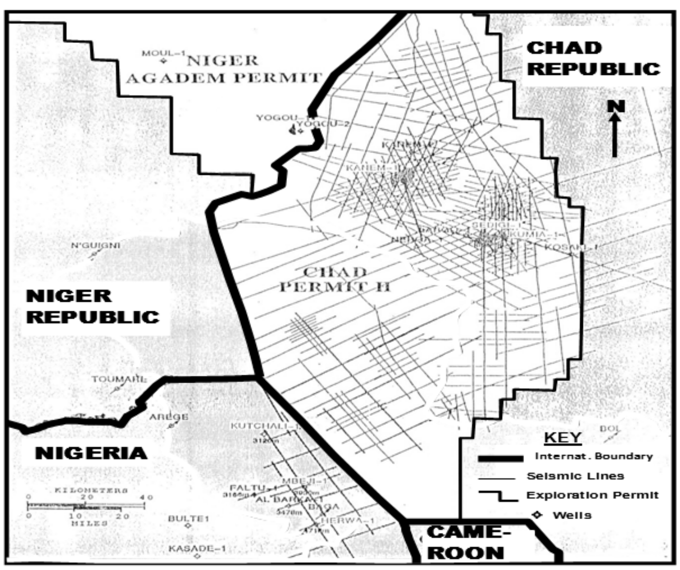



**Fig. 16: 2-D Seismic Density in Bornu Basin, Nigeria and Termit Basin, Chad Republic (from Lake Chad Data Trade).**

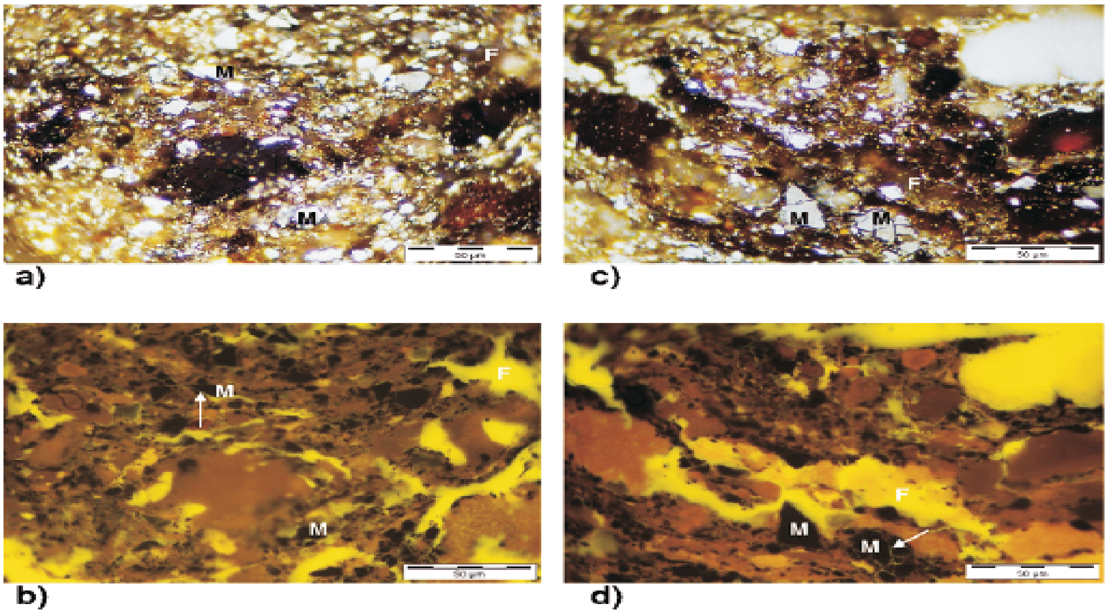



**Plate 1:** Maceral composition of sample NAS 53 under reflected white light (upper) and fluorescent light (lower). (F) Fluorinite perhaps associated with exsudatinite; (M) mineral matter, mainly quartz and clays. Note the infilling (arrow) of the fractures of the mineral matter by fluorinite in (c) and (d).

**Table 1:** Petroleum discovery wells in Niger and Chad Republics showing stratigraphic levels and rock types of reservoirs and the associated petroleum system (data from Genik, 1993).

| Country | Basin | Well Name | Year Drilled | Total Depth (TD) (m) | Age at TD | Rock Type | Results | Petroleum System |
|---|---|---|---|---|---|---|---|---|
| Niger | Termit | Sokor-4 | 1984 | 1870 | Eocene | Continental Clastics | Oil | Palaeogene |
| " | " | Sokor-2 | 1983 | 1895 | " | " | " | " |
| " | " | Goumeri-1 | 1990 | 3280 | Palaeocene | Continental Sandstone | Oil and Gas | " |
| " | " | Sokor-1 | 1982 | 2470 | Maastrichtian | " | Oil | Upper Cretaceous |
| " | " | Madama-1 | 1975 | 3810 | Santonian | Marine Clastics | " | " |
| Chad | " | Sedigi-2 | 1989 | 3048 | Senonian | Marine Sandstone | Oil and Gas | " |
| Niger | " | Yogou-1 | 1979 | 3995 | Coniacian | Marine Clastics | Oil | " |
| Chad | " | Kanem-1 | 1974 | 3726 | " | Marine Sandstone | " | " |
| " | " | Sedigi-1 | 1975 | 3682 | Cen. - Tur. | Marine Clastics | Oil and Gas | Lower Cretaceous |
| " | Doba | Kome-4 | 1989 | 1981 | Cenomanian | Continental Sandstone | Oil | " |
| " | " | Kome-3 | 1989 | 3657 | Albian | Continental Clastics | " | " |
| " | " | Kome-2 | 1985 | 1981 | " | " | " | " |
| " | " | Kome-1 | 1976 | 3055 | " | Continental Sandstone | " | " |
| " | Termit | Kumia-1 | 1976 | 4272 | Albian-Aptian | Continental Clastics | " | " |
| " | Doba | Miandoum-1 | 1974 | 3572 | " | Continental Sandstone | " | " |
| " | " | Bolobo-1 | 1989 | 4095 | Aptian | " | " | " |
| " | Doseo | Kibea-1 | 1986 | 3112 | " | Continental Clastics | " | " |
| " | " | Maku-1 | 1985 | 2056 | " | " | Oil and Gas | " |
| " | " | Tega-1 | 1979 | 3356 | " | " | Oil | " |
| " | Doba | Belanga-1 | 1978 | 3574 | " | " | " | " |
| " | " | Mangara-1 | 1978 | 3234 | " | Continental Sandstone | " | " |

**Table 2: Rock Eval pyrolysis data of samples from Lower Cretaceous - Cenomanian sediments of the northeastern Nigerian Basins.**

| S/N | Sample Name | Sample Locality | Basin/Sub-basin | Formation/Lithology | Age | TOC | S1 | S2 | S3 | Tmax | HI | OI | PI | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KAN-22 | Kanadi Well | Chad | Bima (?Gongila/?Yolde)/Shale | ?Albian - Cenomanian (?Middle) | 0.62 | 0.05 | 0.07 | 0.39 | 467.00 | 11.00 | 63.00 | 0.42 | Olugbemiro, 1997 |
| 2 | KAN-23 | " | " | " | " | 0.72 | 0.16 | 0.30 | 0.62 | 472.00 | 41.00 | 86.00 | 0.35 | " |
| 3 | KAN-24 | " | " | " | " | 0.71 | 0.08 | 0.15 | 0.44 | 475.00 | 21.00 | 62.00 | 0.35 | " |
| 4 | KAN-25 | " | " | " | " | 0.55 | 0.18 | 0.22 | 0.34 | 477.00 | 40.00 | 61.00 | 0.45 | " |
| 5 | KAN-26 | " | " | " | " | 0.71 | 0.35 | 0.24 | 0.43 | 480.00 | 34.00 | 61.00 | 0.59 | " |
| 6 | KAN-27 | " | " | " | " | 0.68 | 0.32 | 0.36 | 0.45 | 482.00 | 52.00 | 66.00 | 0.47 | " |
| 7 | KAN-28 | " | " | " | " | 0.56 | 0.28 | 0.35 | 0.43 | 485.00 | 62.00 | 76.00 | 0.44 | " |
| 8 | KAN-29 | " | " | " | " | 0.22 | 0.23 | 0.25 | 0.59 | 488.00 | 113.00 | 272.00 | 0.48 | " |
| 9 | KIN-24 | Kinasar Well | " | Bima (?Yolde)/Shale | " | 0.51 | 0.15 | 0.22 | 0.19 | 517.00 | 43.00 | 37.00 | 0.41 | " |
| 10 | KIN-25 | " | " | " | " | 0.27 | 0.11 | 0.08 | 0.06 | 522.00 | 30.00 | 22.00 | 0.58 | " |
| 11 | KIN-26 | " | " | " | " | 0.45 | 0.61 | 0.58 | 0.57 | 526.00 | 129.00 | 127.00 | 0.51 | " |
| 12 | KIN-27 | " | " | " | " | 0.35 | 0.68 | 0.48 | 0.37 | 530.00 | 137.00 | 106.00 | 0.59 | " |
| 13 | KIN-28 | " | " | " | " | 0.45 | 0.67 | 0.60 | 0.58 | 532.00 | 133.00 | 129.00 | 0.53 | " |
| 14 | KIN-29 | " | " | " | " | 1.00 | 0.93 | 1.00 | 0.70 | 538.00 | 100.00 | 70.00 | 0.48 | " |
| 15 | KIN-30 | " | " | " | " | 0.21 | 0.45 | 0.38 | 0.14 | 542.00 | 181.00 | 67.00 | 0.54 | " |
| 16 | KIN-31 | " | " | " | " | 0.28 | 0.40 | 0.40 | 0.22 | 548.00 | 143.00 | 79.00 | 0.50 | " |
| 17 | KIN-32 | " | " | " | " | 0.58 | 0.96 | 0.71 | 0.73 | 555.00 | 122.00 | 126.00 | 0.57 | " |
| 18 | KIN-33 | " | " | " | " | 2.09 | 3.27 | 9.09 | 0.37 | 556.00 | 435.00 | 18.00 | 0.26 | " |
| 19 | KIN-34 | " | " | " | " | 0.34 | 1.37 | 0.46 | 0.30 | 560.00 | 135.00 | 88.00 | 0.75 | " |
| 20 | KIN-35 | " | " | " | " | 0.42 | 1.29 | 0.57 | 0.42 | 564.00 | 136.00 | 100.00 | 0.69 | " |
| 21 | KIN-36 | " | " | " | " | 0.61 | 2.36 | 0.88 | 0.58 | 571.00 | 144.00 | 95.00 | 0.73 | " |
| 22 | KIN-37 | " | " | " | " | 0.67 | 2.11 | 0.95 | 0.60 | 575.00 | 142.00 | 90.00 | 0.69 | " |
| 23 | KIN-38 | " | " | " | " | 1.23 | 2.28 | 2.12 | 1.59 | 578.00 | 172.00 | 129.00 | 0.52 | " |
| 24 | KIN-39 | " | " | " | " | 1.18 | 3.08 | 1.76 | 1.25 | 581.00 | 149.00 | 106.00 | 0.64 | " |
| 25 | KIN-40 | " | " | " | " | 0.72 | 2.88 | 1.04 | 0.81 | 586.00 | 144.00 | 112.00 | 0.73 | " |
| 26 | KIN-41 | " | " | " | " | 2.82 | 4.01 | 4.03 | 3.71 | 591.00 | 143.00 | 132.00 | 0.50 | " |
| 27 | NA10 | N. Borehole (GSN1612) | UBT /Gongola | Yolde/Shale | Pre - to M. Cenomanian | 0.56 | 0.03 | 0.24 | | 442.00 | 48.00 | | 0.89 | Akande et al., 1998 |
| 28 | NA12 | " | " | " | " | 12.90 | 4.48 | 22.00 | | 438.00 | 171.00 | | 0.83 | " |
| 29 | NA17 | " | " | " | " | 0.33 | 0.01 | 0.09 | | 437.00 | 27.00 | | 0.90 | " |
| 30 | NA22 | " | " | " | " | 0.89 | 0.06 | 0.49 | | 437.00 | 55.00 | | 0.89 | " |
| 31 | NA23 | " | " | " | " | 0.58 | 0.02 | 0.28 | | 438.00 | 48.00 | | 0.93 | " |
| 32 | NA25 | " | " | " | " | 0.39 | 0.01 | 0.20 | | 442.00 | 55.00 | | 0.95 | " |
| 33 | NA27 | " | " | " | " | 0.10 | 0.00 | 0.11 | | 0.00 | 30.00 | | 1.00 | " |
| 34 | NA29 | " | " | " | " | 0.21 | 0.02 | 0.09 | | 0.00 | 42.00 | | 0.82 | " |
| 35 | YOLD2 | Futuk | " | " | " | 0.35 | 0.01 | 0.11 | 0.12 | 438.00 | 31.00 | 34.00 | 0.92 | Obaje et al., 2004a |
| 36 | YOLD4 | " | " | " | " | 0.30 | 0.01 | 0.08 | 0.19 | 437.00 | 26.00 | 63.00 | 0.89 | " |
| 37 | Nas-35 | Well Nasara -1 | " | Bima/Shale | " | 0.59 | 0.02 | 0.31 | 0.52 | 427.00 | 52.00 | 88.00 | 0.94 | Abubakar et al., 2008 |
| 38 | Nas-36 | " | " | " | " | 0.69 | 0.02 | 0.24 | 0.52 | 428.00 | 35.00 | 75.00 | 0.92 | " |
| 39 | Nas-37 | " | " | " | " | 0.87 | 0.05 | 1.23 | 0.44 | 437.00 | 142.00 | 51.00 | 0.96 | " |
| 40 | Nas-38 | " | " | " | " | 0.55 | 0.02 | 0.70 | 0.52 | 442.00 | 128.00 | 95.00 | 0.97 | " |
| 41 | MYS3 | Gombe | " | " | " | 0.21 | 0.01 | 0.13 | 0.51 | 424.00 | 62.00 | 242.00 | 0.93 | " |
| 42 | Nas-39 | Well Nasara -1 | " | " | " | 0.24 | 0.01 | 0.12 | 0.48 | 445.00 | 50.00 | 201.00 | 0.92 | " |
| 43 | Nas-40 | " | " | " | " | 0.25 | 0.00 | 0.13 | 0.39 | 445.00 | 52.00 | 156.00 | 1.00 | " |
| 44 | Nas-42 | " | " | " | " | 0.38 | 0.07 | 0.61 | 0.76 | 414.00 | 160.00 | 199.00 | 0.90 | " |
| 45 | Nas-43 | " | " | " | " | 0.49 | 0.02 | 0.21 | 0.41 | 463.00 | 43.00 | 84.00 | 0.91 | " |
| 46 | Nas-44 | " | " | " | " | 0.17 | 0.01 | 0.11 | 0.45 | 441.00 | 63.00 | 259.00 | 0.92 | " |
| 47 | Nas-45 | " | " | " | " | 0.30 | 0.02 | 0.26 | 0.55 | 442.00 | 86.00 | 182.00 | 0.93 | " |
| 48 | Nas-46 | " | " | " | " | 0.23 | 0.02 | 0.15 | 0.62 | 443.00 | 65.00 | 270.00 | 0.88 | " |
| 49 | Nas-47 | " | " | " | " | 0.21 | 0.01 | 0.17 | 0.49 | 435.00 | 81.00 | 233.00 | 0.94 | " |
| 50 | Nas-48 | " | " | " | " | 0.21 | 0.02 | 0.17 | 0.43 | 437.00 | 79.00 | 201.00 | 0.89 | " |
| 51 | Nas-49 | " | " | " | " | 0.35 | 0.02 | 0.39 | 0.52 | 432.00 | 113.00 | 151.00 | 0.95 | " |
| 52 | Nas-50 | " | " | " | " | 0.13 | 0.02 | 0.10 | 0.35 | 444.00 | 78.00 | 273.00 | 0.83 | " |
| 53 | Nas-51 | " | " | " | " | 0.13 | 0.01 | 0.08 | 0.30 | 444.00 | 61.00 | 229.00 | 0.89 | " |
| 54 | **Nas-52** | " | " | " | " | 0.33 | 0.06 | 0.39 | 0.48 | 426.00 | 119.00 | 146.00 | 0.87 | " |
| 55 | **Nas-53** | " | " | **Bima/Sand** | " | **52.70** | 20.56 | 297.44 | 10.13 | **427.00** | **564.00** | 19.00 | 0.94 | " |
| 56 | **Nas-54** | " | " | **"** | " | **55.20** | 22.60 | 314.29 | 11.18 | **428.00** | **569.00** | 20.00 | 0.93 | " |
| 57 | Nas-55 | " | " | **"** | " | **52.10** | 18.10 | 306.91 | 10.87 | **423.00** | **589.00** | 21.00 | 0.94 | " |
| 58 | Nas-56 | " | " | Bima/Shale | " | 0.51 | 0.04 | 0.68 | 0.48 | 425.00 | 134.00 | 94.00 | 0.94 | " |
| 59 | Nas-57 | " | " | " | " | 0.18 | 0.01 | 0.10 | 0.45 | 440.00 | 56.00 | 253.00 | 0.91 | " |
| 60 | Nas-58 | " | " | " | " | 0.30 | 0.01 | 0.21 | 0.37 | 446.00 | 70.00 | 124.00 | 0.95 | " |
| 61 | Nas-59 | " | " | " | " | 0.15 | 0.00 | 0.08 | 0.36 | 444.00 | 54.00 | 242.00 | 1.00 | " |
| 62 | Nas-60 | " | " | " | " | 0.25 | 0.00 | 0.07 | 0.36 | 484.00 | 28.00 | 145.00 | 1.00 | " |
| 63 | Nas-61 | " | " | " | " | 0.21 | 0.00 | 0.08 | 0.38 | 466.00 | 38.00 | 182.00 | 1.00 | " |
| 64 | Nas-62 | " | " | " | " | 0.37 | 0.06 | 0.23 | 0.43 | 456.00 | 62.00 | 116.00 | 0.79 | " |
| 65 | Nas-63 | " | " | " | " | 0.10 | 0.01 | 0.04 | 0.38 | 457.00 | 42.00 | 399.00 | 0.80 | " |
| 66 | Nas-64 | " | " | " | " | 0.29 | 0.00 | 0.06 | 0.30 | 514.00 | 21.00 | 104.00 | 1.00 | " |

**Table 3: TOC and extract composition of oil stained samples from the Bima Formation in well Nasara-1.**

| Sample Name | Sample Type | Locality | Formation | Lithology | TOC (wt%) | Extract (mg/g) | Extract (ppm) | Extract (mg/gTOC) | Saturate (%) | Aromatics (%) | Heteropolar (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NAS53 | Oil Stained Sand | Nasara-1 Well | Bima | Sands | 52.70 | 235.74 | 235740 | 239.86 | 14.90 | 5.70 | 74.90 |
| NAS54 | " | " | " | " | 55.20 | 237.19 | 237190 | 447.33 | 16.30 | 5.10 | 78.70 |
| NAS55 | " | " | " | " | 52.10 | 187.58 | 187580 | 429.70 | 13.20 | 5.50 | 81.30 |
| NAS56 | Borehole Cuttings | " | " | Shales | 0.51 | 0.69 | 690 | 360.04 | n.i. | n.i. | n.i. |

NOTE: n.i. = not investigated

**Table 4: Extended hopane distribution of samples from 4710-4770ft in well Nasara-1**

| Sample Name | Sample Type | Locality | Formation | Lithology | H31R/H30 |
|---|---|---|---|---|---|
| NAS53 | Oil stained cuttings | Well Nasara-1 | Bima | Sands | 0.19 |
| NAS 54 | “ | “ | “ | “ | 0.25 |
| NAS53 | “ | “ | “ | “ | 0.27 |

**Table 5:Rock Eval pyrolysis data of samples from Uower Cretaceous sediments of the northeastern Nigerian Basins.**

| S/N | Sample Name | Sample Locality | Basin/Sub-basin | Formation/Lithology | Age | TOC | S1 | S2 | S3 | Tmax | HI | OI | PI | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KM3 | K/Borehole (GSN 4041) | UBT/Gongola | Gombe/Shale | Campanian - Maastrichtian | 1.46 | 0.03 | 0.96 | | 433.00 | 65.00 | | 0.97 | Akande et al., 1998 |
| 2 | KM4 | " | " | " | " | 1.20 | 0.01 | 0.27 | | 422.00 | 22.00 | | 0.96 | " |
| 3 | GMC1 | H/Gari | " | " | " | 0.55 | 0.02 | 0.10 | | 418.00 | 18.00 | | 0.83 | Obaje et al., 1999 |
| 4 | GMC7 | " | " | " | " | 0.25 | 0.01 | 0.10 | | 418.00 | 0.00 | | 0.91 | " |
| 5 | GMC14 | " | " | " | " | 0.20 | 0.01 | 0.00 | | 418.00 | 0.00 | | 0.00 | " |
| 6 | UBHJ 1 | " | " | " | " | 0.92 | 0.01 | 0.03 | 0.47 | 282.00 | 3.00 | 51.00 | 0.75 | Obajeet al., 2004a |
| 7 | UBHJ 2 | " | " | " | " | 0.83 | 0.01 | 0.03 | 0.47 | 300.00 | 4.00 | 57.00 | 0.75 | " |
| 8 | UBHJ 3 | " | " | " | " | 0.96 | 0.01 | 0.03 | 0.43 | 502.00 | 3.00 | 45.00 | 0.75 | " |
| 9 | UBHJ 4 | " | " | Gombe/Coaly Shales | " | 1.05 | 0.01 | 0.03 | 0.37 | 310.00 | 3.00 | 35.00 | 0.75 | Abubakar et al., 2008 |
| 10 | UBWJ1 | W/Sale | " | " | " | 1.26 | 0.01 | 0.05 | 0.67 | 515.00 | 4.00 | 53.00 | 0.83 | Obajeet al., 2004a |
| 11 | UBWJ2 | " | " | " | " | 2.63 | 0.01 | 0.06 | 2.60 | 511.00 | 2.00 | 99.00 | 0.86 | " |
| 12 | UBDJ 1 | D/Borehole | " | " | " | 6.84 | 0.13 | 12.01 | 5.08 | 429.00 | 176.00 | 74.00 | 0.99 | Abubakar et al., 2008 |
| 13 | MGMC3 | " | " | " | " | 3.43 | 0.08 | 9.62 | 1.58 | 432.00 | 280.00 | 46.00 | 0.99 | " |
| 14 | UBDJ 2 | " | " | Gombe/Shaly Coal | " | 20.20 | 0.62 | 35.95 | 10.53 | 423.00 | 178.00 | 52.00 | 0.98 | " |
| 15 | CP8 | G. Maiganga/Borehole | " | " | " | 14.90 | 0.79 | 18.19 | 11.30 | 435.00 | 122.08 | 75.84 | 0.96 | " |
| 16 | CP13 | " | " | " | " | 23.70 | 0.80 | 32.60 | 14.77 | 423.00 | 137.55 | 62.32 | 0.98 | " |
| 17 | FKS5 | Nafada | UBT/Gongola | U.Pindiga/Shale | Cenomanian(Upper) - Santonian | 0.05 | 0.03 | 0.09 | | 591.00 | 180.00 | | 0.75 | Obaje et al., 1999 |
| 18 | FKS9 | " | " | " | " | 0.05 | 0.04 | 0.09 | | 586.00 | 180.00 | | 0.69 | " |
| 19 | FKS11 | " | " | " | " | 0.04 | 0.03 | 0.06 | | 584.00 | 150.00 | | 0.67 | " |
| 20 | FKS14 | " | " | " | " | 0.39 | 0.02 | 0.02 | | 445.00 | 5.00 | | 0.50 | " |
| 21 | KM9 | K/Borehole (GSN 4041) | " | Pindiga/Shale | " | 2.45 | 0.02 | 1.88 | | 435.00 | 76.00 | | 0.99 | Akande et al., 1998 |
| 22 | KM11 | " | " | " | " | 1.63 | 0.01 | 0.22 | | 415.00 | 13.00 | | 0.96 | " |
| 23 | KM13 | " | " | " | " | 1.56 | 0.01 | 0.31 | | 416.00 | 19.00 | | 0.97 | " |
| 24 | KM16 | " | " | " | " | 0.60 | 0.00 | 0.09 | | 423.00 | 15.00 | | 1.00 | " |
| 25 | KM17 | " | " | " | " | 0.74 | 0.02 | 0.10 | | 422.00 | 13.00 | | 0.83 | " |
| 26 | KM18 | " | " | " | " | 0.39 | 0.00 | 0.04 | | 426.00 | 10.00 | | 1.00 | " |
| 27 | KM19 | " | " | " | " | 0.28 | 0.01 | 0.04 | | 0.00 | 14.00 | | 0.80 | " |
| 28 | KM21 | " | " | " | " | 0.65 | 0.00 | 0.09 | | 425.00 | 13.00 | | 1.00 | " |
| 29 | KM23 | " | " | " | " | 0.54 | 0.01 | 0.05 | | 419.00 | 9.00 | | 0.83 | " |
| 30 | KM25 | " | " | " | " | 0.21 | 0.01 | 0.11 | | 0.00 | 0.00 | | 0.92 | " |
| 31 | GB 1 | G/Borehole(GSN1504) | " | " | " | 0.57 | 0.01 | 0.09 | | 426.00 | 15.00 | | 0.90 | " |
| 32 | GB 3 | " | " | " | " | 0.60 | 0.02 | 0.10 | | 423.00 | 24.00 | | 0.83 | " |
| 33 | GB 6 | " | " | " | " | 0.35 | 0.00 | 0.08 | | 428.00 | 22.00 | | 1.00 | " |
| 34 | GB 8 | " | " | " | " | 0.46 | 0.03 | 0.08 | | 421.00 | 17.00 | | 0.73 | " |
| 35 | GB 10 | " | " | " | " | 0.47 | 0.01 | 0.08 | | 422.00 | 23.00 | | 0.89 | " |
| 36 | GB 13 | " | " | " | " | 0.49 | 0.02 | 0.18 | | 424.00 | 36.00 | | 0.90 | " |
| 37 | GB 14 | " | " | " | " | 0.45 | 0.01 | 0.07 | | 419.00 | 16.00 | | 0.88 | " |
| 38 | GB 16 | " | " | " | " | 0.32 | 0.01 | 0.07 | | 425.00 | 21.00 | | 0.88 | " |
| 39 | GB 17 | " | " | " | " | 0.48 | 0.01 | 0.14 | | 419.00 | 29.00 | | 0.93 | " |
| 40 | GB 19 | " | " | " | " | 0.43 | 0.01 | 0.07 | | 419.00 | 16.00 | | 0.88 | " |
| 41 | GB 21 | " | " | " | " | 0.42 | 0.02 | 0.08 | | 425.00 | 19.00 | | 0.80 | " |
| 42 | GB 22 | " | " | " | " | 0.40 | 0.00 | 0.15 | | 420.00 | 37.00 | | 1.00 | " |
| 43 | GB 26 | " | " | " | " | 0.38 | 0.01 | 0.15 | | 423.00 | 39.00 | | 0.94 | " |
| 44 | GB 28 | " | " | " | " | 0.46 | 0.02 | 0.14 | | 424.00 | 30.00 | | 0.88 | " |
| 45 | GB 31 | " | " | " | " | 0.40 | 0.01 | 0.11 | | 424.00 | 27.00 | | 0.92 | " |
| 46 | AS1 | AshakaQuarry | " | " | " | 0.41 | 0.00 | 0.10 | | 423.00 | 24.00 | | 1.00 | " |
| 47 | AS2 | " | " | " | " | 0.26 | 0.00 | 0.04 | | 431.00 | 15.00 | | 1.00 | " |
| 48 | DA 7 | Pindiga | " | " | " | 2.13 | 0.07 | 0.73 | | 424.00 | 34.00 | | 0.91 | Obaje et al., 1999 |
| 49 | DA 11 | " | " | " | " | 2.08 | 0.07 | 0.63 | | 423.00 | 32.00 | | 0.90 | " |
| 50 | DA 12 | " | " | " | " | 1.94 | 0.05 | 0.32 | | 419.00 | 16.00 | | 0.86 | " |
| 51 | GGS3 | AshakaQuarry | " | " | " | 0.52 | 0.01 | 0.09 | | 418.00 | 17.00 | | 0.90 | " |
| 52 | GGS12 | " | " | " | " | 0.50 | 0.02 | 0.10 | | 419.00 | 20.00 | | 0.83 | " |
| 53 | GGS13 | " | " | " | " | 0.51 | 0.02 | 0.07 | | 418.00 | 14.00 | | 0.78 | " |
| 54 | GGL16 | " | " | " | " | 0.10 | 0.01 | 0.02 | | 483.00 | 20.00 | | 0.67 | " |
| 55 | GGS17 | " | " | " | " | 0.57 | 0.04 | 0.19 | | 417.00 | 33.00 | | 0.83 | " |

| S/N | Sample Name | Sample Locality | Basin/Sub-basin | Formation/Lithology | Age | TOC | S1 | S2 | S3 | Tmax | HI | OI | PI | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 56 | GGS21 | AshakaQuarry | UBT/Gongola | Pindiga/Shale | Cenomanian (Upper) - Santonian | 0.46 | 0.02 | 0.05 | | 416.00 | 11.00 | | 0.71 | Obaje et al., 1999 |
| 57 | PIND10 | Pindiga | " | " | " | 0.71 | 0.02 | 0.22 | 0.36 | 418.00 | 31.00 | 51.00 | 0.92 | Obaje et al., 2004a |
| 58 | GONG1 | AshakaQuarry | " | " | " | 0.59 | 0.02 | 0.12 | 0.35 | 419.00 | 20.00 | 60.00 | 0.86 | " |
| 59 | GONG2 | " | " | " | " | 0.52 | 0.01 | 0.09 | 0.26 | 420.00 | 17.00 | 50.00 | 0.90 | " |
| 60 | GONG3 | " | " | " | " | 0.53 | 0.01 | 0.08 | 0.32 | 417.00 | 15.00 | 61.00 | 0.89 | " |
| 61 | GONG4 | " | " | " | " | 0.55 | 0.02 | 0.14 | 0.33 | 421.00 | 26.00 | 61.00 | 0.88 | " |
| 62 | Nas-1 | Well Nasara-1 | " | " | " | 0.67 | 0.01 | 0.12 | 0.40 | 419.00 | 18.00 | 60.00 | 0.92 | Abubakar et al., 2008 |
| 63 | Nas-2 | " | " | " | " | 0.87 | 0.02 | 0.29 | 0.67 | 420.00 | 33.00 | 77.00 | 0.94 | " |
| 64 | Nas-3 | " | " | " | " | 0.65 | 0.01 | 0.20 | 0.31 | 420.00 | 31.00 | 48.00 | 0.95 | " |
| 65 | Nas-4 | " | " | " | " | 0.63 | 0.01 | 0.14 | 0.41 | 420.00 | 22.00 | 65.00 | 0.93 | " |
| 66 | Nas-5 | " | " | " | " | 0.55 | 0.01 | 0.08 | 0.34 | 421.00 | 15.00 | 62.00 | 0.89 | " |
| 67 | Nas-6 | " | " | " | " | 0.51 | 0.01 | 0.08 | 0.34 | 423.00 | 16.00 | 67.00 | 0.89 | " |
| 68 | Nas-7 | " | " | " | " | 0.64 | 0.01 | 0.16 | 0.36 | 421.00 | 25.00 | 57.00 | 0.94 | " |
| 69 | Nas-8 | " | " | " | " | 0.58 | 0.01 | 0.11 | 0.34 | 423.00 | 19.00 | 59.00 | 0.92 | " |
| 70 | Nas-9 | " | " | " | " | 0.66 | 0.01 | 0.10 | 0.25 | 424.00 | 15.00 | 38.00 | 0.91 | " |
| 71 | Nas-10 | " | " | " | " | 0.58 | 0.01 | 0.11 | 0.38 | 424.00 | 19.00 | 65.00 | 0.92 | " |
| 72 | Nas-11 | " | " | " | " | 0.46 | 0.01 | 0.10 | 0.36 | 427.00 | 22.00 | 78.00 | 0.91 | " |
| 73 | Nas-12 | " | " | " | " | 0.45 | 0.00 | 0.08 | 0.37 | 426.00 | 18.00 | 82.00 | 1.00 | " |
| 74 | Nas-13 | " | " | " | " | 0.51 | 0.01 | 0.10 | 0.34 | 424.00 | 20.00 | 67.00 | 0.91 | " |
| 75 | Nas-14 | " | " | " | " | 0.56 | 0.01 | 0.13 | 0.57 | 420.00 | 23.00 | 102.00 | 0.93 | " |
| 76 | Nas-15 | " | " | " | " | 0.57 | 0.01 | 0.14 | 0.44 | 421.00 | 24.00 | 77.00 | 0.93 | " |
| 77 | Nas-16 | " | " | " | " | 0.55 | 0.01 | 0.15 | 0.56 | 424.00 | 27.00 | 102.00 | 0.94 | " |
| 78 | Nas-17 | " | " | " | " | 0.59 | 0.01 | 0.15 | 0.39 | 420.00 | 26.00 | 66.00 | 0.94 | " |
| 79 | Nas-18 | " | " | " | " | 0.53 | 0.01 | 0.13 | 0.57 | 424.00 | 25.00 | 108.00 | 0.93 | " |
| 80 | Nas-19 | " | " | " | " | 0.48 | 0.01 | 0.14 | 0.47 | 423.00 | 29.00 | 98.00 | 0.93 | " |
| 81 | Nas-20 | " | " | " | " | 0.50 | 0.01 | 0.14 | 0.47 | 423.00 | 28.00 | 93.00 | 0.93 | " |
| 82 | Nas-21 | " | " | " | " | 0.44 | 0.01 | 0.10 | 0.35 | 424.00 | 23.00 | 79.00 | 0.91 | " |
| 83 | Nas-22 | " | " | " | " | 0.44 | 0.01 | 0.11 | 0.46 | 424.00 | 25.00 | 104.00 | 0.92 | " |
| 84 | Nas-23 | " | " | " | " | 0.45 | 0.01 | 0.09 | 0.31 | 425.00 | 20.00 | 69.00 | 0.90 | " |
| 85 | Nas-24 | " | " | " | " | 0.40 | 0.01 | 0.09 | 0.37 | 426.00 | 22.00 | 92.00 | 0.90 | " |
| 86 | Nas-25 | " | " | " | " | 0.54 | 0.01 | 0.14 | 0.55 | 422.00 | 26.00 | 102.00 | 0.93 | " |
| 87 | Nas-26 | " | " | " | " | 0.59 | 0.01 | 0.14 | 0.31 | 419.00 | 24.00 | 53.00 | 0.93 | " |
| 88 | Nas-27 | " | " | " | " | 0.59 | 0.01 | 0.17 | 0.51 | 420.00 | 29.00 | 86.00 | 0.94 | " |
| 89 | Nas-28 | " | " | " | " | 0.46 | 0.01 | 0.16 | 0.51 | 426.00 | 35.00 | 110.00 | 0.94 | " |
| 90 | Nas-29 | " | " | " | " | 0.50 | 0.02 | 0.26 | 0.48 | 429.00 | 52.00 | 96.00 | 0.93 | " |
| 91 | Nas-30 | " | " | " | " | 0.53 | 0.02 | 0.30 | 0.55 | 427.00 | 57.00 | 104.00 | 0.94 | " |
| 92 | Nas-31 | " | " | " | " | 0.75 | 0.03 | 0.58 | 0.40 | 430.00 | 77.00 | 53.00 | 0.95 | " |
| 93 | Nas-32 | " | " | " | " | 0.71 | 0.03 | 0.48 | 0.53 | 433.00 | 68.00 | 75.00 | 0.94 | " |
| 94 | Nas-33 | " | " | " | " | 0.58 | 0.03 | 0.33 | 0.63 | 432.00 | 57.00 | 108.00 | 0.92 | " |
| 95 | Nas-34 | " | " | " | " | 0.59 | 0.01 | 0.29 | 0.45 | 433.00 | 50.00 | 77.00 | 0.97 | " |
| 96 | MPS20 | Pindiga water borehole | " | " | " | 0.30 | 0.06 | 0.08 | 0.31 | 421.00 | 26.00 | 102.00 | 0.57 | " |
| 97 | MPS50 | " | " | " | " | 0.57 | 0.02 | 0.20 | 0.34 | 421.00 | 35.00 | 60.00 | 0.91 | " |
| 98 | MPS63 | " | " | " | " | 0.52 | 0.02 | 0.20 | 0.27 | 417.00 | 38.00 | 52.00 | 0.91 | " |
| 99 | MPS70 | " | " | " | " | 0.47 | 0.01 | 0.15 | 0.28 | 419.00 | 32.00 | 59.00 | 0.94 | " |
| 100 | MPS72 | Gombe | " | " | " | 0.64 | 0.02 | 0.21 | 0.33 | 421.00 | 33.00 | 52.00 | 0.91 | " |
| 101 | MPS77 | Bdbaya | " | " | " | 0.23 | 0.01 | 0.02 | 0.32 | 476.00 | 9.00 | 139.00 | 0.67 | " |
| 102 | MGS5 | AshakaQuarry | " | " | " | 0.42 | 0.01 | 0.06 | 0.34 | 421.00 | 14.00 | 81.00 | 0.86 | " |
| 103 | MGS2 | " | " | " | " | 0.50 | 0.01 | 0.11 | 0.22 | 423.00 | 22.00 | 44.00 | 0.92 | " |
| 104 | MGS1 | " | " | Pindiga/Calcareous Shale | " | 0.37 | 0.01 | 0.15 | 0.64 | 425.00 | 40.00 | 171.00 | 0.94 | " |
| 105 | KIN-3 | Kinasar Well | Chad | Fika/Shale | Cenomanian (Upper) - Santonian | 0.95 | 0.04 | 0.47 | 0.61 | 429.00 | 49.00 | 64.00 | 0.08 | Olugbemiro, 1997 |
| 106 | KIN-4 | " | " | " | " | 0.75 | 0.05 | 0.42 | 0.72 | 428.00 | 56.00 | 96.00 | 0.11 | " |
| 107 | KIN-5 | " | " | " | " | 0.77 | 0.04 | 0.19 | 0.48 | 429.00 | 25.00 | 62.00 | 0.17 | " |
| 108 | KIN-6 | " | " | " | " | 1.14 | 0.08 | 0.77 | 0.42 | 434.00 | 67.00 | 36.00 | 0.09 | " |
| 109 | KIN-7 | " | " | " | " | 0.92 | 0.07 | 0.46 | 0.49 | 432.00 | 50.00 | 53.00 | 0.13 | " |
| 110 | KIN-8 | " | " | " | " | 0.54 | 0.04 | 0.14 | 0.46 | 435.00 | 25.00 | 85.00 | 0.22 | " |
| 111 | KIN-9 | " | " | " | " | 1.57 | 0.45 | 1.67 | 0.62 | 440.00 | 106.00 | 39.00 | 0.21 | " |
| 112 | KIN-10 | " | " | " | " | 1.01 | 0.23 | 0.85 | 0.64 | 443.00 | 84.00 | 63.00 | 0.21 | " |

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# A Sustainable Electrical Energy Consumption and Production Development Pathway for Nigeria: A Case Study of Energy Recovery from Agro-forestry Wastes

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## ABSTRACT

Nigeria is endowed with various conventional and non-conventional energy resources essential for a robust and rapid economic growth and development. However, there is a high degree of infrastructural deficiency in the economy particularly in the electricity sector. This study is an effort to carry out a quantification assessment of the sawdust and rice husk generated in the sawmills and ricemills respectively and their corresponding electrical energy potential in each of the identified clusters. Based on these potentials, the capacity of the power plant was determined. In addition, a load survey in the beneficiary area and the agro-forestry clusters themselves were conducted so as to identify potential site which is not far away from the fuel source for the location of the power plant. Finally, the study also carried out quantification of $CO_2$ emission minimization capacity and economic gains from fuel displacement based on the usage of sawdust and rice husk to generate electricity. Based on an estimated total volume of wood waste in excess of 212,220 $m^3$ (about 66,000 tons) per annum and at about 30% efficiency, about 8.0 MW of electric power will be generated with an annual electricity output of about 79,089.3 MWh. Similarly, based on the estimated 55,000 tonnes of annually generated rice husk, and at an overall plant efficiency of 20-24%, a 5 MW rice husk fired power plant is being proposed for ricemill clusters. In monetary term, diesel displaced by the sawdust based power plant is about N177 million (about US$1.3 million) while that of rice husk fired plant is in excess of N236 million (US$2 million) per annum for each of the clusters studied. In addition, $CO_2$ emissions that will be saved through these projects have been estimated to be in excess of 73,000 tons $CO_2$/year, making them good candidates for Clean Development Mechanism (CDM) projects.

*Keywords: Sawmill, Ricemill, Wood Wastes, Rice Husk, Wood Waste-Power Generating System, Rice Husk fired Power Plant, Socio-economic Benefits, Environmental Benefits, $CO_2$ Emissions, Clean Development Mechanism*

## 1.0 INTRODUCTION

The provision of adequate, affordable, accessible and sustainable electricity supply is critical to the attainment of the broad goals of high and sustainable human development. Electricity interacts with human development at different levels and, facilitates economic development and poverty reduction by underpinning industrial growth and enhancing productivity [1]. A careful study of the pattern of electricity consumption vis-à-vis economic growth across different countries shows oscillation around an initial cluster characterized by low energy consumption, economic stagnation and energy infrastructural decay. Most countries experienced this cluster very early in their developmental stages. However, with the right strategy, many countries have broken through the cluster to achieve an increasingly sustained path of energy consumption and economic growth. Examples of these countries include, Iran, Malaysia and Chile

Economic history clearly shows that power has served as catalyst for economic growth and development. The level of electricity consumption closely mirrors the level of economic development of a nation. Figure 1 gives the graphical illustration of the interrelationship between electricity consumption and economic growth. The cross country data shows Nigeria at the bottom of the ladder with relatively low per capita income and low per capita electricity consumption, while Singapore occupies the top right position with high per capita income and high per capita electricity consumption. The close correlation between power consumption and economic growth has also been demonstrated in the Nigerian case. The peak of Nigeria economic growth 1970-79 and 2002-2004 are also associated with the highest growth in electricity generation in Nigeria. However, the low investment, and inefficient institutional structure have been the bane of the sector and kept the sector from performing its growth-inducing and welfare improving roles.

Power development therefore has a key role to play in Nigeria's economic development process. It has the capacity to serve either as a catalyst or a fetter on the wheels of economic development. With a population in excess of 140 million people and abundant fossil and renewable energy resources, Nigeria's installed power generating capacity is less than 6,000 MW and average available capacity is less than 1700 MW, representing about 28% capacity utilization. Table 1 reveals that in 2001, the national electrical energy produced per capita was 0.16 KWh while the electrical energy consumed per capita was 0.11 KWh. Comparatively with some other countries whether advanced, newly industrialized or developing, Nigeria's figures are incredibly lower. An evidence of the impact of the poor quality, unreliability and limited availability of power supply on Nigeria's economic development is its debilitating effects on the industrialization process. Nigerian manufacturers have consistently identified poor power supply as the most important constraint to their business. Majority of them have to supplement publicly supplied electricity with very expensive auto-generation. For instance, based on a sample of 232 firms in a study by the World Bank [2], 94% of them reported that infrastructure is their biggest problem (which is 2.5 times more worrisome than finance) and 97% of the firms own generators. Removing the constraint of unreliable power generation will therefore enhance the microeconomic response of the real sector to the various incentives embodied in the National Economic Empowerment and Development Strategy (NEEDS). It will also enhance the realization of the objectives of the Millenium Development Goals (MDGs) and the goals of NEEDS which include wealth creation, employment generation and poverty reduction.

## 2.0 HISTORICAL TREND OF ELECTRICITY PRODUCTION AND CONSUMPTION

The historical electricity generation, including purchases from independent generators (NESCO, Shell (SPDC) and Ajaokuta Steel Co.), as well as electricity sales are given in Figure 2. The total generation showed vigorous double-digit annual growth rate over the 1970s, with an average of 15.3% for the years 1973-1980. The growth slowed down in each of the next two decades to averages of 6.6% over 1981-1990 and 1.3% over 1991-2000. These corresponded generally to the growth of investments in generating capacity. The low generation growth in the 1990s period, with frequent negative annual growths, reflected the poor state of the plants and lack of funding of the electric utility during the period. The growth of grid electricity sales showed similar trends as those for generation, with average annual percentage growths of 13.6%, 6.0% and 0.8% over the decades (1971-1980), (1981-1990) and (1991-2000) respectively. The average of sales growth rates, though slightly lower, closely matched the averages of growth rates in generation. This indicates that sales and consumption of electricity were constrained by generation. Notwithstanding recent developments in the power sector, the imbalance between supply and demand for electricity is still very high and there is the need to explore other power generation options.

## 3.0 SOCIO-ECONOMIC DEVELOPMENT OF AREAS OF STUDY

The focus of this study is on productive use of sawdust and rice husk. Sawdust, one major byproduct of wood processing, is produced extensively in forested areas of Nigeria in large quantities and mostly burnt as waste. Also, rice husk is generated during the process of milling dried parboiled paddy rice from the fields. The husk is discarded in designated rice husk dumpsites where mounds of the husk quickly develop. To reduce mound size, the mound is openly burnt from time to time. The burning of these wastes has attracted attention and is viewed as a potential means of generating electricity to augment the epileptic national grid supply, and also provide alternative source of energy to hydrocarbons in various communities in Nigeria. On the environmental issue, the use of sawdust and rice husk is also seen as a potential means of achieving $CO_2$ reduction to the atmosphere from energy usage.

The areas of study are located in Ogun and Ebonyi states. **Ogun State** is a state in South-western Nigeria. The State has a total land area of 16,762 km$^2$ and borders Lagos State to the south, Oyo and Osun states to the North, Ondo State to the east and the Republic of Benin to the west. Abeokuta is the capital and largest city in the state. The State is made up of 20 local government areas. The study area in the state covers four local government councils of the Ijebu area namely, Ijebu Ode, Ijebu North,, Ijebu North East and Odogbolu.Total population of the study area based on 2006 National Population Commission census exercise is put at 673,125 [3]. This is broken down as follows: Ijebu Ode LGA - 154,032; Ijebu North - 284,336; Ijebu North East - 67,634; and Odogbolu - 127,123 persons respectively. Agriculture is the main occupation engaged in by the people of Ijebu, but in recent times the people have also been involved in trading and manufacturing. Ebonyi state is located in the south eastern region of Nigeria and is bounded to the north by Benue State, to the west by Enugu State, to the east by Cross River State and to the south by Abia State. With a land area of about 5,935 sq. km, the state lies approximately within longitude 7°30' and 8°30'E and latitude 5°40' and 6°45'N. There are thirteen Local Government Areas (LGAs) in the state. The study area in the state is Abakaliki LGA. Ebonyi State has a population size of 2.58 million consisting of about 205,848 households. It is a rural state with about 70% of the people dwelling in the rural areas. A recently concluded State Energy Survey gives a revelation of the economic status of the people of the state. The survey revealed that 70% of the population is in the low income bracket while 25% and 5% are in the middle and high income brackets respectively. Economic activities of the people include subsistence farming, animal husbandry, trading, and civil/public service. The three primary and leading agro-allied industries in the State are processing of paddy rice, wood saw milling/wood product carpentry works and cassava processing to produce garri (a staple food). The development of the agro-based industries in the state will both facilitate its industrial development and enhance the standard of living of its people.

## 4.0 METHODOLOGY

The goal of this study was to quantify the amount of energy available for electricity generation using sawdust from the over 100 sawmill found in Ijebu area and rice husk generated from the ricemills in Abakaliki LGA, and also assess their $CO_2$ minimization capacities. Based on this, the study specific objectives were taken to be: assess and quantify the sawdust and rice husk generated and the electrical energy potentials of these wastes in each identified cluster; determine the capacity of the power plant based on energy potential of sawdust and rice husk generated; conduct a load survey of power demand in the beneficiary area and identified clusters; and quantify the $CO_2$ emission minimization to be achieved using sawdust and rice husk to generate electricity for operating the sawmills and rice mills. To achieve this goal, partially structured questionnaire was adopted as research instrument [4] designed through field survey to elicit relevant information from the various categories of stakeholders. From the quantification exercise, the $CO_2$ minimization capacity for utilizing sawdust and rice husk powered electricity generation was carried out based on Hagan [5]. To ensure adequate coverage for the data gathering process for the proposed power plant using wood wastes and particularly sawdust in the Ijebu area and rice husk in Abakaliki area, a participatory approach was adopted involving all stakeholders. The stakeholders include Sawmillers' and Rice Millers' Associations, sawmill and rice mill owners and/or operators, local authorities both traditional and modern (that is the traditional rulers and local government Chairmen), the Chambers of Commerce, a Non-Governmental

Organization (NGO)-Justice, Development and Peace Commission (JDPC), National Electric Utility Company-Power Holding Company of Nigeria (PHCN) – Ijebu District, and the National Population Commission (NPC) in the study areas. Specific questions within the questionnaire were designed to meet the research objectives. For the local authorities and the Chambers of Commerce, the questions directed at them were mostly those that relate with interest in the proposed power plant and desire to contribute to its successful implementation. Specific questions related to power demand and supply situation in the study areas were directed at the PHCN while questions relating to raw materials required, wastes generated, grid electrical energy demand, alternative source of electricity generation, quantity of fuels used for self generation, etc were directed to the sawmiller and ricemiller associations and sawmill and ricemill owners and operators. The returned questionnaires were examined for completeness and usability. Usable returned questionnaires were coded and entered into a computer spreadsheet for analysis.

The Ijebu area of Ogun State covering four local government areas with over 200 towns, villages and communities is home to quite a number of sawmills making use of wood from the vast forest resources in the area which in turn produces large quantities of sawdust. Several clusters of sawmills in Ijebu Ode, Ijebu North, Ijebu North East and Odogbolu Local Government Areas (Ijebu Igbo, Obalende, Egirin Road, Oke-Owa and Orilonise clusters) were identified for quantification of sawdust generated from their sawmill industry. Abakaliki Local Government area (LGA) consisting of Abakaliki Township and Ekumenyi were identified for quantification of rice husk generated from the ricemills.

## 5.0 RESULTS AND ANALYSIS

### 5.1 QUANTIFICATION OF SAWDUST GENERATED AND ENERGY POTENTIALS

Altogether there are about 100 sawmills operating under the umbrella of Saw-millers' Associations in each of the clusters. Quantification of sawdust generated from each sawmill was done using plant visit, peer conversations, data/information from the questionnaire to owner and/or operator of sawmills and calculations were subsequently based on related literature (from scientific journals, etc) accessed from the Internet [6]. The plant visit gave insight to how the waste produced in each sawmill is disposed of. Equivalent of bags used to package 50 kg rice in the market are usually used by women employed to sweep the sawdust from the mills daily. In each sawmill visited, it was estimated that the bags evacuated are between 100 and 120 bags per day per sawmill. Each sawmill employs an average of 4 workers per day for the purpose of keeping the working area free of wastes. A bag filled with sawdust was weighed and found to be about 20 kg and its volume was calculated to be about $0.082m^3$. It was estimated that each sawmill produces an average of 110 bags/day. This will amount to approximately 2.2 tons of sawdust per day per sawmill. Thus the total amount of sawdust that would be produced by all the clusters of sawmills covered in the study is estimated at about 220 tons per day. Quite a sizeable amount of this sawdust is burnt off by sawmillers in order to avoid the problems of dumping, groundwater as well as air pollution. To estimate the volume of wood produced in each sawmills was challenging as most of the respondents could not give a clear estimate of the volume of logs that come for processing despite the fact that they could readily account for the number of logs. Since the logs are not of the same volume from the forest, a proxy based on total amount of sawn-wood per band saw per working day was then applied to estimate the volume of wood produced per sawmill. It was discovered that operating at optimal level, each band saw is capable of producing about 350 $ft^3$ or 9.45 $m^3$ of wood per day. This is estimated to need about 760 $ft^3$ of wood-log per day. Despite the epileptic electricity supply however, it was revealed through interview with the operators that most sawmills, operating with only a band saw, could still produce at a minimum of 200 $ft^3$ or 5.4 $m^3$ of wood per day. Wood-logs processed in all sawmills located in the study area are air-dried. The operations of these mills depend heavily on electricity mostly powered by electricity from diesel-fuelled generators and supply from the national grid. It is estimated that sawmills spend an average of N9,000 ($72.30) for 100 litres of diesel per day (which amounts to about N5.4 million per week for the 100 mills) aside from the average of N22,000.00 ($186.44)/month paid to utility for electricity supply per sawmill. On a monthly basis, electricity/energy related expenses of the saw-millers is estimated at approximately N238, 000.00 ($2,017) (or N23.8 ($0.21) million on energy/electricity related expenses by the 100 sawmills) depending on the number of saws operated by sawmill. Ample experiences abound in other parts of the world especially Asian countries such as India and some African countries (Ghana) on the utilization of sawdust as fuel for electricity and steam generation. It is hoped that the same experience could be replicated in Ijebu area to provide reliable, affordable, sustainable, and adequate electricity supply to the area. This is with the aim that utilizing sawdust for electricity generation will stimulate industrial growth and in turn affect economic development of the area and at the same time create a benign environment for human existence. Table 2 highlights the breakdown of sawmills in each of the clusters, while Table 3 shows breakdown of saws found in these clusters. Table 4 summarizes the average volume of log handled daily in each cluster while Table 5 presents estimated average volume of wastes generated aily in each of these clusters.

### 5.2 ELECTRICITY DEMAND AND SUPPLY IN IJEBU AREA

The study area falls under the precinct of the Ijebu Ode District of PHCN. The peak electricity demand for the entire district is put at 51 MW. This peak demand is met with 30 MW supply from PHCN which represents 59% with the remaining supply coming from self-generated electricity [7]. Weekly energy supply to the district from the national grid is put at 2,500 GWh. Total number of customers in the district is put at 49,106. This is broken down into 82.7%, 17.1% and 0.2% for residential (low voltage), commercial (medium voltage) and industrial (high voltage) customers respectively. Metered customers are 70.1% while the un-metered customers are put at 29.9%. Number of unplanned outages per year is put at 126 with the duration put at 469 hours per year. Fault and load shedding are the two main reasons given for causes of major power outages in the district. However, there is no record of the total volume of unplanned outages per year and there is no record also for the number of complaints related to deficient services in the district. Based on the amount of energy received from the national grid, the annual revenue expected is put at N45,378,234.54($384,561.30) whereas revenue collected is put at N33, 691,922.68 ($285,524.80). This puts the annual revenue loss for this district at about 26% of expected revenue.Some information regarding electricity supply situation based on field survey are presented in Figure 3 and Table 6 respectively.

### 5.2.1 Power Demand/Supply Situation in Sawmill industry

As stated earlier, sawmill industry in Ijebu Area is a major industry affecting the income earning capacity of quite a number of its inhabitants. PHCN places the power demand from sawmill industry under commercial (medium voltage) customer category. Also, as highlighted earlier, the typical energy requirements to run the sawing machines of small- and medium-size sawmills are only mechanical as typified in the schematic diagram in Figure 4. Typical prime movers in these sawmills are powered by electricity. The energy requirement for processing in sawmills depend on the type of wood, product type, the equipments used, and the factory size. Average energy consumption by the industry differs based mainly on the units of band and circular saws in each sawmill (Table 7). The survey indicated that Ijebu Igbo cluster with the highest number of band and circular saws has the highest electricity demand amongst the clusters. The survey revealed that out of the four clusters, the least demand for electricity was made by Obalende cluster. Total electricity used in sawmill clusters per day was estimated based on a 10 working hour per day. The result for each cluster is presented in Table 8. From the administered survey questionnaire, the average tariff charged by PHCN for the medium voltage customer is N8.50/kWh ($0.072/kWh). Average daily energy consumption by sawmills in each cluster, split into grid and self-generation is presented in Table 9. Peer conversations with owners/operators in each of the clusters of sawmill during the field survey revealed that hardly does the PHCN supply electricity from the grid to power their saws for operation. 90% of their operations are carried out with electricity supplied from their standby diesel fueled generators. Table 10 presents the estimated cost of daily diesel consumption for each of the clusters with the total cost at almost N600, 000 ($5,084.75) per day. This, they reasoned had added significantly to their cost of production and consequently eroded their profit margin.

## 5.3 ESTIMATED CAPACITY OF PROPOSED POWER PLANT USING THE SAWDUST GENERATED

From Table 7, the power demand for the clusters of sawmill in Ijebu Area is estimated at a little over 5.5 MW. Out of this, Ijebu Igbo presently has the highest power demand with a little over 2 MW. All the visited sawmills in Ijebu Area operate mainly with band and circular saws which require electricity to run. The electricity supply at the visited sawmill factory is provided from the PHCN grid through a step-down power transformer with capacity of 400 kVA. During all the periods the visits lasted to the clusters of sawmill, most of the transformers were disconnected by PHCN due mostly to load shedding. As highlighted earlier, 90% of power used for each of the saws comes from installed standby generators within each sawmill.Based on discussion with operators of sawmills, it was estimated that the power demand of each sawmill (if all equipments work in parallel) is about 700 kVA. The distribution of saws per cluster of sawmill is presented in Table 11. In order to achieve an equivalent of the present production level of approximately 700 $m^3$ sawn-timber per-day (see Table 4), the sawmill industry at Ijebu area will require to process approximately 1,500 $m^3$ wood-log per-day. From this total amount of wood process daily, it was estimated that the total wood waste that would be produced by the clusters of sawmill is 800 $m^3$/day. If we assume that 20% of the waste is used by local community as firewood for cooking then about 640 $m^3$/day is left in the clusters of sawmill or about 176 tons of wood-wastes per day. As for diesel consumption, using a daily consumption of 50 litres for the operation of one band-saw and one circular-saw respectively for 10 hours, it is estimated that this is equivalent to approximately 19,650 kWh per month. With about 100 sawmill establishments in Ijebu Area, the total volume of sawn timber production is estimated at about 212,220 $m^3$/year. The average sawn timber production for each factory would then be about 2,122 $m^3$/year per-sawmill. Sawmills in this area are powered with electric driven band and circular saws with power capacity of 30 kW and 22.5 kW respectively.Though specific energy consumption for each saw in the study area was not taken, a proxy study [8] was used to estimate this value to be about 65 kWh/m$^3$-sawn timbers produced. The specific energy production from the waste is estimated at about 80 kWh/m$^3$-sawn timbers. Thus, the generated waste can fulfill the energy demand of the mill if it is utilized.

### 5.4 TECHNICAL CHARACTERISTICS OF PROPOSED SAWDUST FUELED POWER PLANT

To estimate electricity capacity to be generated from sawdust, some characteristics have to be considered as these differ in woods and their residues based on species and origin or location. In Table 12 are presented the average characteristics of Ghanaian wood and their residues (close to Nigerian woods), wood processing residue samples including sawdust as determined in laboratory studies. On the average, the thermal value quoted for wood residues (including sawdust) as fuel is 15,000kJ/kg. In sawmill terms this equates to 875.7 kWh/m$^3$. Plants generating electricity from wood normally operate at thermal efficiencies between 30% and 60% depending on plant composition. With the estimated average volume of sawdust produced annually at 212,220 m$^3$ and assuming an efficiency of 30%, the equivalent electrical potential from the sawdust generated annually at MOW is 212,220 m$^3$ x 875.7 kWh/m$^3$ x 0.30 ≥ 55,752,316.2 kWh. All scheduled maintenance is to be carried out only on Sundays and a forced outage rate of 42 hours/month is assumed. For a plant operating at 7008 hours annually (Table 11), the corresponding size of the power plant would be:

Sawdust usually presents disposal problems for wood processing firms and it is assumed that all the quantity needed for the plant would be

$$55{,}752{,}316.2\ \text{kWh} \big/ 7008\text{h} \geq 8.0\ \text{MW}$$

fetched and/or purchased at minimal cost from the many wood processing firms in the area to allow this power production. From a similar pre-feasibility assessment on such wood waste power systems done for Indonesian wood products industry, all scheduled maintenance could be conducted on Sundays and a forced outage rate of 6% of the annual hours could be expected for well-maintained plants [9]. According to this Indonesian report, worldwide experience reveals that scheduled maintenance requires about 5% of the annual hours, which amounts to 36.5 hours per month. Thus, the scheduled maintenance on Sundays (104 hours/month) and a forced maintenance period of 6% of the annual hours (42 hours/month) assumed in this pre-feasibility report study for the proposed power plant for Ijebu Area is adequate. Altogether the plant for Ijebu Area would be operating for 7,008 hours annually. For the financial analysis, the factors to be considered under the financial analysis include capital cost of proposed plant, project financing (debt and equity ratio to be determined at feasibility study level), expected revenue from proposed plant and project analysis.

### 5.5 ESTIMATE OF POTENTIAL GENERATING CAPACITY FROM THE FIELD SURVEY

Field survey to Ijebu Area indicates that the volume of wood wastes presently generated in the clusters of sawmill is enough to attract the location of power plants utilizing sawdust and other wood wastes. Table 12 highlights the electricity generation potential of each cluster and the wood factories based on the volume of wastes they generate and the generator capacity that would be installed for this purpose. For the proposed power plant, a Combined Heat and Power (CHP) plant, that is, a co-generation plant may be better than the conventional power and heat generating options due to some factors which include:

· The relatively lower capital investment of a co-

generation plant.
· Its reduced fuel consumption
· Its reduced environmental pollution.
In addition, energy through co-generation could be used to produce steam for:

· Steaming peeler blocks for plywood manufacture.
· Drying of lumber especially in these saw mills where drying of lumber is solely done by sun drying. This takes longer time and the quality of the end product is not good enough as to attract considerable price.
· Production of electrical power to reduce the mills dependency on the national grid.

## 5.6 PROJECT BASELINE GREENHOUSE GASES (GHG) EMISSION CALCULATION

The project boundary (see Figure 3) excludes the product of both processes that are out of the physical boundary. This means that anything that happens outside of sawmill is excluded. Landfill or burning by the people in surrounding areas will not be part of the calculations of the potential GHG emission. The boxes with colours are the components of GHG emission/saving calculations. Figure 4 shows three components: electricity from grid, diesel generators and wood wastes that are staying in the factory. The project will replace electricity supply from grid, mechanical energy from diesel generators and avoid wood waste from being dumped. The two aspects regarding baseline emissions are local emissions and distance emissions. The local emissions are due to wood waste dumping and the use of diesel generators. Distance emissions are due to electricity generation in the Power Holding Company of Nigeria System.

### 5.6.1 Local Emissions

If the project is not implemented in the project area, two things will happen to wood wastes. The first is wood burning and the second is wood dumping. The sawdust/wood chips are usually just dumped. The calculation here is based on the sawdust/wood chips percentage. Burning the wood waste will emit important GHG gasses such as $CH_4$, $N_2O$, CO, and NOx, ($CO_2$ emission is compensated by the sequestered $CO_2$) while dumping the sawdust could emit $CH_4$ from the decomposition process. This means keeping the wood waste inside the factory and not dumping it will prevent the emission of GHG gasses outside the project boundary. Keeping the waste inside the factory does not keep the wood waste from decomposing. From the mass balance in Figure 4 and Table 4, we can see that in sawmills from 100% log, 50% of it becomes waste. Out of 100% log, around 10% becomes sawdust and wood chips. Saw dust and wood chips are usually dumped and burnt. 10% of raw material is 21,222 $m^3$ of wood chips and sawdust. Using 210-kg/$m^3$ specific weight factors, the volume will weigh around 4,456.62 tons/year. The emission factor of waste dumping is 1.5 tons $CO_2$/ton waste [10] Using this number it means that the sawmills can emit more about 6,685 **tons $CO_2$ eq/year**. The cluster break down of $CO_2$ emissions based on Table 5 is given in Table 14. Table 14 also gives a breakdown of the total avoided $CO_2$ emissions, 13,076.3 tons $CO_2$/year according to emission sources.

## 5.7 QUANTIFICATION OF RICE HUSK GENERATED AND ENERGY POTENTIALS

From all the local government areas, about 218,622 tonnes of paddy rice are processed to yield about 147,570 tonnes of white rice annually. The production of rice husk from the processed paddy rice is estimated to be about 54,656 tonnes on an annual basis in the State. The study further revealed that the installed capacity of rice mills in Ebonyi State in the period April-July 2005 was more than 2.0 million tonnes of paddy rice per year, while the capacity utilization presently is just about 10%. The implication of this is that at least 10 times the quantity of rice husk generated presently can still be obtained at full capacity utilization of the existing rice mills in the state. Analysis of the survey data revealed several interesting characteristics and potential opportunities for rice milling sector in the state. Table 15 gives a summary of information and data on rice milling facilities, direct workforce employed in rice milling, estimates of paddy rice processed, white rice and rice husk produced, by each local government area (LGA) in the State. Cumulatively, about 55,000 tonnes of rice husk is generated annually from the rice mills in Ebonyi State. About 82%of these is generated in Abakaliki LGA where the largest rice milling cluster is located (Figure 6 shows a dump site for rice huk in Abakaliki). Information gathered during the survey indicated that only 5% of rice husk produced is being used as fuel for residential and commercial cooking stoves and as livestock feeds. The rest has been accumulated at open disposal sites, near the large rice mill cluster in Abakaliki. At these disposal sites, people scavenged for remnant of white rice that has been disposed with the husk. During summer, the accumulated husk mountains often catch fire with attendant environmental consequences and risk to scavenging people. Currently the rice processing facilities face the problem of limited availability of paddy rice (current mill capacity utilization is as low as 10% and the mill is run for 5 hour per day). However, information from stakeholders indicates that the paddy rice production in the State can be doubled to about 300,000 tonnes per annum. Medium to large-scale rice milling activities can be found in two locations in Abakaliki LGA, specifically in Abakaliki and Ekumeniyi townships. In Abakaliki, the rice-milling cluster is located on Ogoja Road while in Ekumenyi, the major cluster is at Nwida Market square. The rice processing facility in Abakaliki Township is the largest in Ebonyi State. It is a cluster with about **1000 milling machines and 30 destoning machines**. The rice mill as well as the de-husking area, currently covers a total of about 10 square kilometer. The following assumptions were generated from the data collected during the field survey and utilized in the estimation of rice husk production on an annual basis at the Abakaliki Township cluster:

Each of the milling machine at the cluster has an installed capacity of about 0.8 tonnes of semi-polished rice per hour;

There are 1000 milling machines in the cluster;

Over the past few years, the milling machine has been averaging a capacity utilization of about 10%. Each milling machine currently operates for about 5 hours per day and 300 days per year;

For each tonne of paddy rice, between 0.65-0.70 tonnes of white rice and between 0.22-0.28 tonnes of rice husk are produced.

Rice milling facilities are also located in Ekumenyi in Abakaliki LGA. Ekumenyi is made up of four major communities namely: Edda; Amachi; Ndegukpetumo and Ndebookpetumo. There are a total of about 10 rice-milling machines. Over 99% of rice produced in Abakaliki LGA comes from the rice mill cluster in Abakaliki cluster with the Ekumenyi facilities yielding only marginal additions. Due to poor and inadequate grid electricity supply, these mills which run essentially on diesel drives spend in excess of N236 million (US$2 million) annually on diesel. Given the above estimate of annual paddy rice production in the State, it can be concluded that about 73% of paddy rice produced in the State is milled; It was also concluded from the survey exercise during interactive discussions with knowledgeable stakeholders that if a waste to energy project is sited in Ebonyi State, rice husks produced in other States not far from the facility are likely to be transported to the site to derive value from the otherwise valueless materials.

## 5.8 ELECTRICITY DEMAND AND SUPPLY IN EBONYI STATE

Presently, electricity from the national grid is transmitted and distributed to towns and some local government areas of the state. The load demand for electricity in Ebonyi State is estimated at 30 MW covering only the areas hooked to the national grid. Electricity supply in the state is obtained from a 132 KV substation situated at Mile 50 Abakaliki. The total supply of electricity to Ebonyi State is 24 MW. In addition to electricity supply from the national grid, the State Government is making some efforts at rural electrification in the State. In this regard, there are various rural electrification projects at various development stages in various local government areas of the State. Some are funded by the Government and some are being executed through African Development Bank (ADB) assistance. Although agro-industries are well established in the State, these are based on old technologies which are characterized by low production and inefficient energy use. These have led to a lot of generated wastes which are not being converted to energy or any economic use. The impact of these on the environment where such facilities are located is substantial.

## 5.9 ELECTRICAL ENERGY DEMAND OF THE RICE MILLS

Electrical energy required for the milling operations averaged about 35.6 GWh/year. This does not include energy used in the parboiling and drying of the paddy rice prior to being supplied to the mill. The existing rice processing cottage industry set-up is very energy inefficient. For instance, UNIDO study [11], revealed that while the specific energy requirement (including energy for parboiling and drying of the paddy rice) of a modern rice mill ranges between 30-60 kWh per tonne of paddy rice processed, in Ebonyi State this has been estimated to be about 158 kWh per tonne of paddy rice processed. This figure does not even include energy utilized for parboiling and drying of paddy rice and it's between 3-5 times that of the modern mill, revealing the enormous quantity of energy being wasted through inefficient technology. When the rice husk is used as a fuel in a conventional steam cycle power plant, with a fuel throughput rate of 6.63 tonnes/hr, a power rating of the resulting system has been estimated to be about 6.6 MW. A variant of the system above is one where 30% of the steam produced is extracted to be utilized for non-power purposes (e.g. parboiling of paddy rice), the output will include, 4.6 MW power and 92 GWh/yr of heat energy. However, when the rice husk is used as a fuel in a combined heat and power system the rating will depend on the heat to power ratio: for a H:P ration of 3:7, 147 MW of power and 44.32 GWh/yr of steam will be produced; when the H:P ratio is 3:2, power production will be about 8.4 MW and the steam rate will be 88.64 GWh/yr; When the gasification technology is utilized to produce power only, system rating will be about 11MW.

## 5.10 ETIMATED CAPACITY OF PROPOSED POWER PLANT USING THE RICE HUSK GENERATED

Rice husk powered power plant is a proven technology and more than 100 such plants are already in operation in other parts of the world, though there are limited suppliers of utility boilers. There are successful rice husk power plants in South East Asia countries like Malaysia, Thailand. Based on the estimated 55,000 tonnes of annually generated rice husk, a 5 MW rice husk fired power plant is being proposed for the Abakaliki rice mill cluster [12].

## 5.11 TECHNICAL CHARACTERISTICS OF PROPOSED RICE HUSK FUELED POWER PLANT

With a plant life of 20 years, a gross power generation of 5 MW and plant consumption of 0.5 MW, the plant's net power generation is 4.5 MW. While the boiler efficiency (LHV %) ranges between 80-85%, the overall plant efficiency (LHV %) ranges between 20-24 % This plant with a total investment cost of US$ 11.26 is expected to run for 8,000 hours requirng between 48,000-56,000 tonnes of rice husk annually. The land required is about 2 hectares.

### 5.12 SOCIO-ECONOMIC AND ENVIRONMENTAL BENEFITS OF PROPOSED PROJECT

As a low NOx and SOx technology, the avoidable total greenhouse gas emissions accruing from this project is about 60,000 tonnes of $CO_2$ equivalent annually. Under the Clean Development Mechanism (CDM), this will give 60,000 CER per year. Apart from revenue from sales of generated electricity, at €10 per CER, total revenue from CER is €600,000 per annum. This revenue is possible for the next 21 years [12]. In addition; about 9,600 tons of rice husk ash will be generated from the project. There is a global demand for rice husk ash particularly in Japan, North America, Europe, Korea, Taiwan, Australia and New Zealand. It is being used in the steel, cement, fertilizer, refractory, brick making, die-casting, semiconductor, rubber and oil recycling industries as well as poultry farms. However, the demand for this rice husk is still unknown and its quality is yet to be ascertained. The international price for rice husk ash ranges between US$50-120/ton [13]. Using a modest figure of US$50 per ton, additional revenue of US$480,000 will accrue from rice husk ash sale annually.

## 6.0 CONCLUSION

Sawmill industry in Ijebu Area and ricemill industries in Abakaliki LGA contribute significantly to the economic well being of their communities. As is with various other industries and business concerns, these industries are suffering from acute shortage of electricity for operations as most of their operations are electricity dependent. Sawdust and rice husks are major by products of these industries and about 80% of these by products are currently being burnt as wastes, since there is no means of utilizing them within the industries and around the study area. In quantifying the amounts of sawdust and rice husk produced per cluster in the study areas, it was estimated that a total volume of wood waste produced is a little over 212,220 $m^3$ (about 66,000 tons) and about 55,000 tons of rice husk per annum. At 80% gasification efficiency [8], the produced wood wastes have been estimated to be capable of providing fuel to power 8.0 MW generating plant with an annual electricity output of about 79,089.3 MWh. Similarly, based on the estimated 55,000 tonnes of annually generated rice husk, and at an overall plant efficiency of 20-24%, a 5 MW rice husk fired power plant is being proposed for ricemill clusters. This study reveals that there are considerable socio-economic and environmental benefits that these projects will bring to both the immediate communities and direct beneficiaries as well as to Ogun and Ebonyi States and the country, generally. Implementation of these project has the potentials of saving at least 6,550 litres of diesel consumption daily at the sawmills. In monetary terms, this translates to about N600, 000 per day and N177 million per annum. At the ricemills, the cost savings of the diesel displaced is in excess of N236 million. These cost savings, it is believed will increase the profit margin of the sawmill and ricemill operators. The benefits of the project from the environmental perspective include:

· replacement of electricity supply from the national grid to the sawmills,

· replacement of diesel fueled self-generated electricity,

· avoidance of dumping of wood wastes to the earth.

The $CO_2$ emissions that will be saved through these activities that will be avoided have been estimated to be in excess of 73,000 tons $CO_2$/year, which make them good candidates for Clean Development Mechanism (CDM) projects. These are just clusters in only one area of the States of areas of study, with clusters of sawmills and ricemills scattered across the country, many of these projects could be established given the enabling environment. Excess electricity after the sawmills and ricemills have been duly satisfied can be wheeled to other small and medium scale enterprises (SMEs) around the mills as well as neighbouring households electricity consumers. However, to maximize the benefits of these projects, the sawmills and ricemills need to adopt energy efficient equipments. In order to attract investors into the electricity sector and particularly these projects, the electricity tariff regimes have to be market driven for the investors to make good returns on their investments. With the ongoing reforms and restructuring in the electricity

Table 1: Electrical Energy Production and Consumption in Selected Countries around the world (2001)

| Country | Electrical Energy Produced/Capita (KWh/Cap) | Electrical Energy Consumed/Capita (KWh/Cap) |
|---|---|---|
| **A. Some G8 Countries** | | |
| **Canada** | **17.4** | **15.5** |
| **USA** | **12.7** | **12.3** |
| **France** | **8.6** | **6.9** |
| **Japan** | **8.1** | **7.6** |
| **Germany** | **6.6** | **6.2** |
| **B. Some Australasian Countries** | | |
| **Australia** | **9.95** | **9.26** |
| **Taiwan** | **6.60** | **6.20** |
| **South Korea** | **6.00** | **5.60** |
| **C. Some Latin American Countries** | | |
| **Paraguay** | **7.25** | **6.43** |
| **Venezuela** | **3.50** | **3.30** |
| **Chile** | **2.63** | **2.54** |
| **Argentina** | **2.50** | **2.40** |
| **D. Some African Countries** | | |
| **South Africa** | **4.60** | **4.20** |
| **Libya** | **3.60** | **3.33** |
| **Egypt** | **0.99** | **0.92** |
| **Algeria** | **0.77** | **0.71** |
| **Ghana** | **0.42** | **0.40** |
| **Morocco** | **0.45** | **0.41** |
| **Nigeria** | **0.16** | **0.11** |

**Source: Dayo, 2005**

Table 2: Number of Sawmill per Cluster

| **Cluster code[1]** | **Cluster name** | **Number of Sawmill** |
|---|---|---|
| OdgLGA | Ejirin Road | 29 |
| IjNLGA | Ijebu Igbo | 42 |
| IjNELGA | Oke Owa | 23 |
| IjOLGA | Obalende | 2 |
| Others | Wood Factories | 4 |
| | **Total** | **100** |

Table 3: Number of Saws in Each Sawmill Cluster

| **Cluster code** | **Cluster name** | **# of Band** | **% of Total** | **# of Circular** | **% of Total** |
|---|---|---|---|---|---|
| OdgLGA | Ejirin Road | 47 | 36 | 47 | 36 |
| IjNLGA | Ijebu Igbo | 50 | 38 | 50 | 38 |
| IjNELGA | Oke Owa | 27 | 21 | 27 | 21 |
| IjOLGA | Obalende | 4 | 3 | 4 | 3 |
| Others | Orilonise Wood Factory | 3 | 2 | 3 | 2 |
| | **Total** | | | | |

OdgLGA ≥ Odogbolu Local Government Area; IjNLGA ≥ Ijebu North Local Government Area; IjNELGA ≥ Ijebu North East Local Government Area; IjOLGA ≥ Ijebu Ode Local Government Area

Table 4: Average Volume of Log Handled Daily Per Cluster

| **Cluster code** | **Cluster name** | **Actual volume of wood processed per day $m^3$/day)**[1] | **Yearly production capacity ($m^3$/year)** | **Potential volume of wood that can be processed per day ($m^3$/day)** | **Yearly production ($m^3$/year)** |
|---|---|---|---|---|---|
| OdgLGA | Ejirin Road | 444 | 133,245 | 254 | 76,140 |
| IjNLGA | Ijebu Igbo | 473 | 141,750 | 270 | 81,000 |
| IjNELGA | Oke Owa | 255 | 76,545 | 146 | 43,740 |
| IjOLGA | Obalende | 38 | 11,340 | 22 | 6,480 |
| Others | Orilonise Wood Factory | 28 | 8,505 | 16 | 4,860 |
| | **Total** | **1,237.95** | **371,385** | **707** | **212,220** |

Table 5: Estimated Average Volume of Wastes (Chippings, Shavings and Sawdust) Produced Daily Per Cluster ($m^3$/day)

| **Cluster code** | **Cluster name** | **Quantity of Sawdust Produced per Day ($m^3$/day)** | **Yearly Production ($m^3$/year)** |
|---|---|---|---|
| OdgLGA | Ejirin Road | 25.4 | 7,614 |
| IjNLGA | Ijebu Igbo | 27.0 | 8,100 |
| IjNELGA | Oke Owa | 14.6 | 4,374 |
| IjOLGA | Obalende | 2.2 | 648 |
| Others | Orilonise Wood Factory | 1.6 | 486 |
| | **Total** | **70.7** | **21,222** |

Table 6: Customer and Tariff Distribution under Ijebu Ode District of PHCN

| **Customer Type** | **# in Group** | **Tariff Amount (N/kWh)** |
|---|---|---|
| Residential (LV) | 40,579 | From 1.2 to 8.5 |
| Commercial (MV) | 8,415 | 8.5 |
| Industrial (HV) | 94 | From 6.5 to 8.5 |
| **Total** | **49,088** | - |

Table 7: Estimated Power Demand in Each Cluster of Sawmill

| **Cluster code** | **Cluster name** | **Power demand from saws (kW)** | **Other ancillary equipment (kW)** | **Total Power Demand (kW)** |
|---|---|---|---|---|
| OdgLGA | Ejirin Road | 1,513.8 | 37.7 | 1,551.5 |
| IjNLGA | Ijebu Igbo | 2,088.0 | 52.0 | 2,140.0 |
| IjNELGA | Oke Owa | 1,409.4 | 35.1 | 1,444.5 |
| IjOLGA | Obalende | 208.8 | 5.2 | 214.0 |
| Others | Orilonise Wood Factory | 156.6 | 3.9 | 160.5 |
| | **Total** | **5,376.6** | **133.9** | **5,510.5** |

Table 8: Estimated Energy Demand Based on Total Power Demand in Table 7 in Each Cluster of Sawmill

| **Cluster code** | **Cluster name** | **Electricity Demand (kWh/day)** |
|---|---|---|
| OdgLGA | Ejirin Road | 15,515 |
| IjNLGA | Ijebu Igbo | 21,400 |
| IjNELGA | Oke Owa | 14,445 |
| IjOLGA | Obalende | 2,140 |
| Others | Orilonise Wood Factory | 1,605 |
| | **Total** | **55,105** |

Table 9: Source of Electricity Supply to Each Sawmill in Each Cluster

| **Cluster code** | **Cluster name** | **Electricity Demand met from Grid (kWh/day)** | **Electricity Demand met through Standby Generators (kWh/day)** |
|---|---|---|---|
| OdgLGA | Ejirin Road | 1,551.5 | 13,963.5 |
| IjNLGA | Ijebu Igbo | 2,140.0 | 19,260.0 |
| IjNELGA | Oke Owa | 1,444.5 | 13,000.5 |
| IjOLGA | Obalende | 214.0 | 1,926.0 |
| IjNELGA | Orilonise Wood | 160.5 | 1,444.5 |
| | **Total** | **5,510.5** | **49,594.5** |

Table 10: Estimated Daily Diesel Consumption per Cluster

| Cluster code | Cluster name | # of Band | Diesel Consumption | Daily Amount | Annual Amount N |
|---|---|---|---|---|---|
| OdgLGA | Ejirin Road | 47 | 2,350 | 211,500.00 | 63,450,000.00 |
| IjNLGA | Ijebu Igbo | 50 | 2,500 | 225,000.00 | 67,500,000.00 |
| IjNELGA | Oke Owa | 27 | 1,350 | 121,500.00 | 36,450,000.00 |
| IjOLGA | Obalende | 4 | 200 | 18,000.00 | 5,400,000.00 |
| Others | Orilonise Wood | 3 | 150 | 13,500.00 | 4,050,000.00 |
| | **Total** | | **6,550** | **589,500.00** | **176,850,000.00** |

Table 11: Distribution of Saws Operated in Each Cluster of Sawmill

| Cluster code | Cluster name | 1 Unit of Saws | % of Total | 2 Units of Saws | % of Total | 3+ Units of Saws | % of Total |
|---|---|---|---|---|---|---|---|
| OdgLGA | Ejirin Road | 15 | 51 | 10 | 34 | 4 | 14 |
| IjNLGA | Ijebu Igbo[1] | 25 | 52 | 15 | 31 | 8 | 17 |
| IjNELGA | Oke Owa | 18 | 67 | 7 | 26 | 2 | 7 |
| IjOLGA | Obalende | 0 | - | 2 | 100 | 0 | 0 |
| IjNELGA | Orilonise Wood Factory | 0 | 0 | 0 | 0 | 3 | 100 |
| | **Total** | 58 | | 34 | | 17 | |

Table 12: Nominal Characteristics of Some Wood Processing Industry Residues

| | |
|---|---|
| Green Moisture Content (Wet basis) | 36% |
| Green density | 210 kg/$m^3$ |
| Volatiles | 8.3% |
| Ash Content | 1.6% |
| Higher Heating Value (HHV) (Oven dry ) | 20.0 MJ/kg |
| Lower Heating Value (LHV) | 11.9 MJ/kg |

Table 13: Estimated Electricity Generation Potential and Generator Capacity for Each Cluster

| **Cluster code** | **Cluster name** | **Quantity of Sawdust Produced per Day ($m^3$/day)** | **Electricity Generation Potential (kWh)** | **Required Generator Capacity** |
|---|---|---|---|---|
| OdgLGA | Ejirin Road | 254 | 68,719.7 | 2.9 |
| IjNLGA | Ijebu Igbo | 270 | 99,525.1 | 3.0 |
| IjNELGA | Oke Owa | 146 | 54,501.8 | 1.6 |
| IjOLGA | Obalende | 22 | 9,478.6 | 0.2 |
| Others | Orilonise Wood Factory | 16 | 4,739.3 | 0.2 |
| | **Total** | **707** | | **8.0** |

Table 14: Estimated Total Avoided $CO_2$ Emissions (tons/year) from the Three Identified Sources per Cluster

| Cluster code | Cluster name | Avoided $CO_2$ Emissions from Waste Dump to the Earth (tons/year) | Avoided $CO_2$ Emissions from Diesel fuelled Self Generating | Avoided $CO_2$ Emissions from the National Grid Supply (tons/year) | Total tons $CO_2$/year |
|---|---|---|---|---|---|
| OdgLGA | Ejirin Road | 2,398.4 | 1,854.2 | 344.4 | **4,597.0** |
| IjNLGA | Ijebu Igbo | 2,551.5 | 1,972.5 | 475.1 | **4,999.1** |
| IjNELGA | Oke Owa | 1,377.8 | 1,065.2 | 320.7 | **2,763.7** |
| IjOLGA | Obalende | 204.1 | 157.8 | 47.5 | **409.4** |
| Others | Orilonise Wood Factory | 153.1 | 118.4 | 35.6 | **307.1** |
| | **Total** | **6,684.9** | **5,168.1** | **1,223.3** | **13,076.3** |

**Table** 15: Rice Milling Facilities and Rice Processing in Ebonyi State by LGA

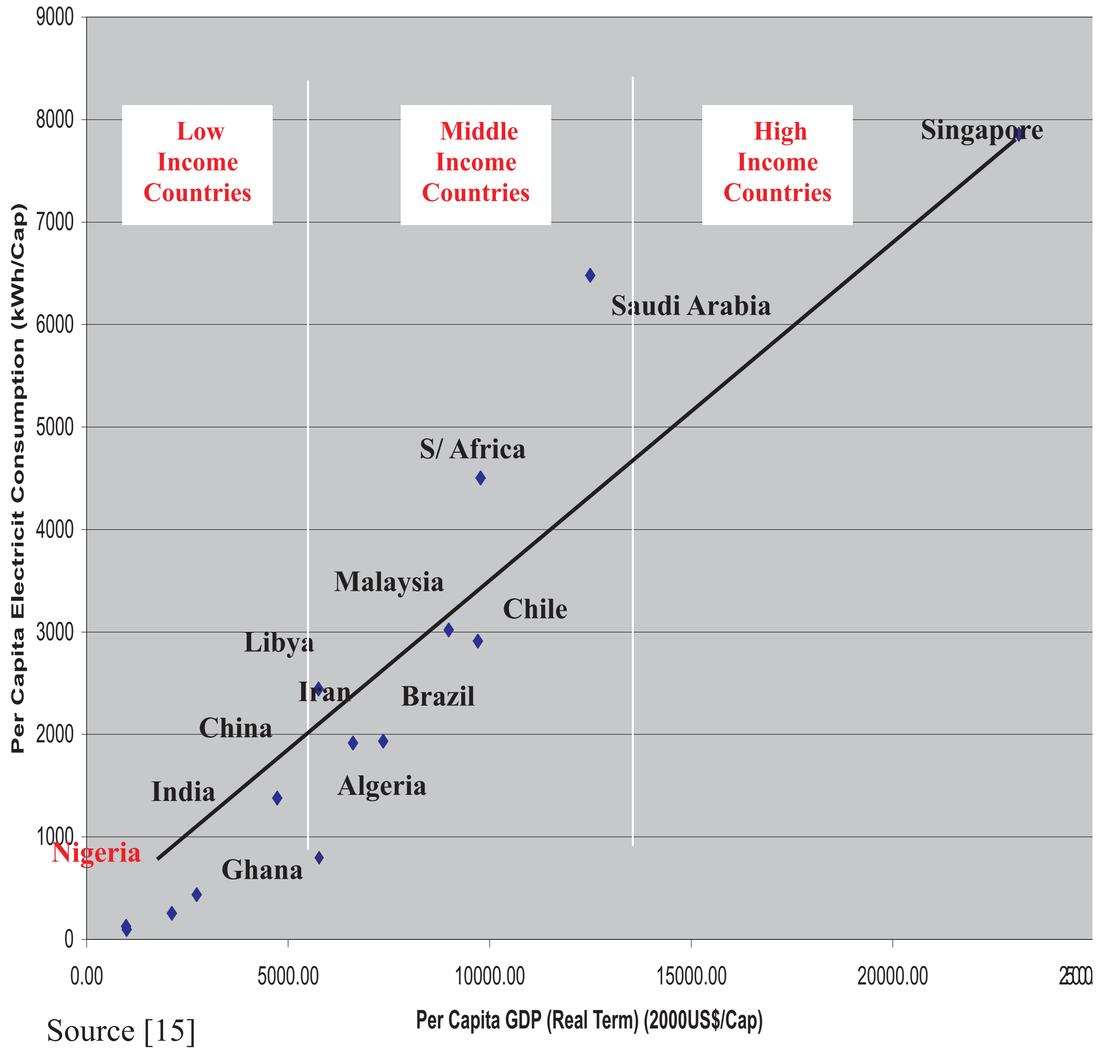
| **No.** | **Name of LGA** | **No. of Mills** | **No. of De-stoning Machines** | **No. of Direct Milling Personnel** | **Paddy Rice Input (Tonnes per annum)** | **White Rice Rice Produced (Tonnes per annum)** | **Rice Husk Produced (Tonnes per annum)** |
|---|---|---|---|---|---|---|---|
| **1.** | Abakaliki* | 1010 | 30 | 5050 | 179,555.56 | 121,200.00 | 44,888.89 |
| **2.** | Afikpo North* | 27 | 0 | 135 | 3,600.00 | 2,430.00 | 900.00 |
| **3.** | Afikpo South | 3 | 0 | 15 | 400.00 | 270.00 | 100.00 |
| **4.** | Ebonyi | 13 | 0 | 65 | 1,733.33 | 1,170.00 | 433.33 |
| **5.** | Izzi* | 15 | 0 | 75 | 2,000.00 | 1,350.00 | 500.00 |
| **6.** | Ezza South* | 24 | 0 | 120 | 3,200.00 | 2,160.00 | 800.00 |
| **7.** | Ezza North* | 40 | 0 | 200 | 5,333.33 | 3,600.00 | 1,333.33 |
| **8.** | Ikwo | 56 | 0 | 280 | 7,466.67 | 5,040.00 | 1,866.67 |
| **9.** | Ivo* | 38 | 0 | 190 | 5,066.67 | 3,420.00 | 1,266.67 |
| **10.** | Ohazara | 7 | 0 | 35 | 933.33 | 630.00 | 233.33 |
| **11.** | Ohaukwu* | 38 | 0 | 190 | 5,066.67 | 3,420.00 | 1,266.67 |
| **12.** | Onicha* | 21 | 0 | 105 | 2,800.00 | 1,890.00 | 700.00 |
| **13.** | Ishielu | 11 | 0 | 55 | 1,466.67 | 990.00 | 366.67 |
| | **TOTAL** | **1,303.00** | **30** | **6,515** | **218,622.22** | **147,570.00** | **54,655.56** |

· **Sites with Mill Clusters**

Table 16: Present Rice and Husk Production in Abakaliki LGA

| **Location** | **Paddy Rice Input** (Tonnes/year) | **Rice Husk Produced** (Tonnes/year) | **White Rice Production** (Tonnes/year) |
|---|---|---|---|
| Abakaliki Township | 172,900.8 | 43,245.2 | 116,800.0 |
| Ekumenyi | 1,297.0 | 324.3 | 876.0 |
| **Total** | **174,197.8** | **43,569.5** | **117,676.0** |

Source [11]




Source [15]

Figure 1: Per Capita Electricity Consumption versus Per CapitaGDP Real Term 2003 for Some Selected Countries

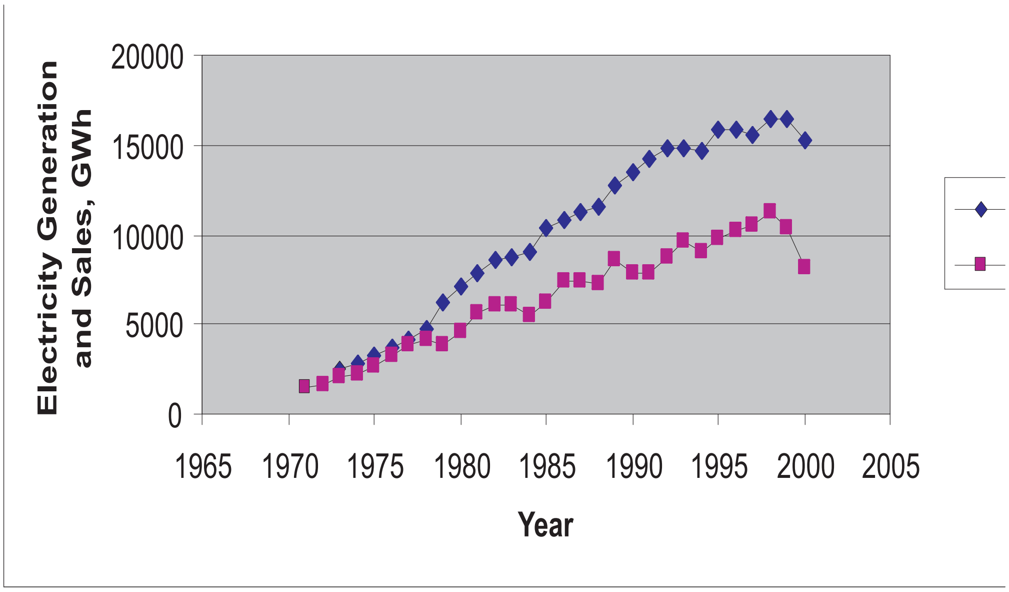



**Figure 2:** Electricity Generation and Sales

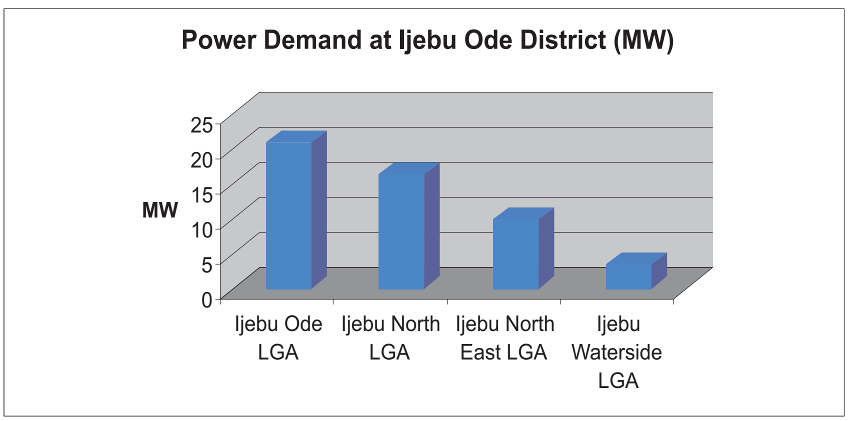



**Figure 3:** Power Demand in Ijebu Ode District of PHCN [24]

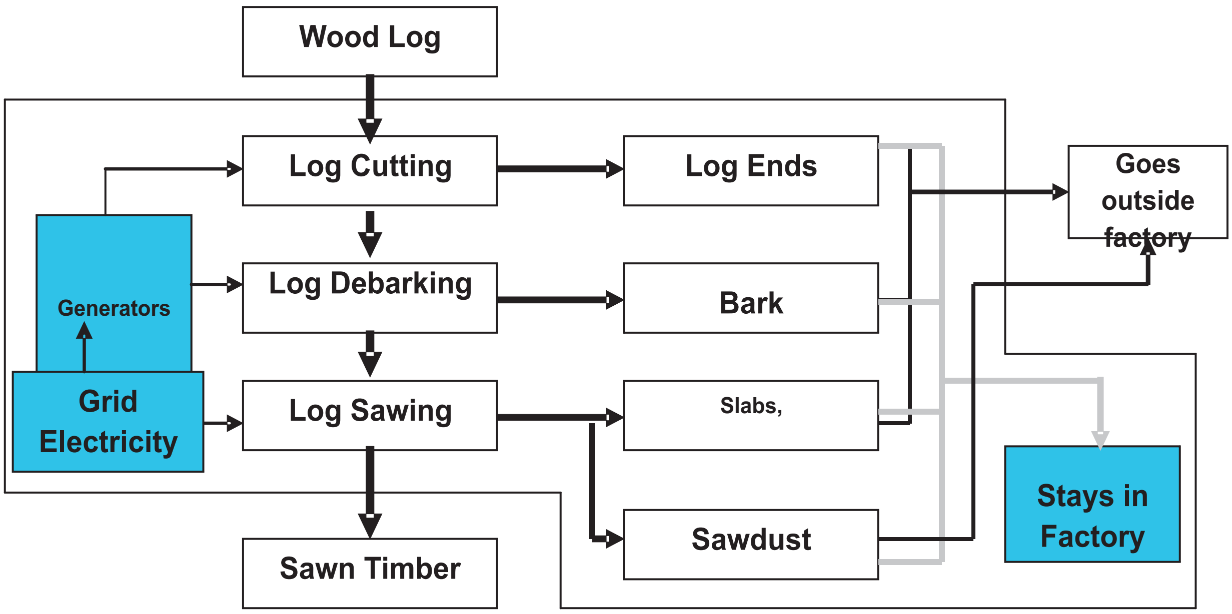



**Figure 4:** Power Demand in Ijebu Ode District of PHCN[24]

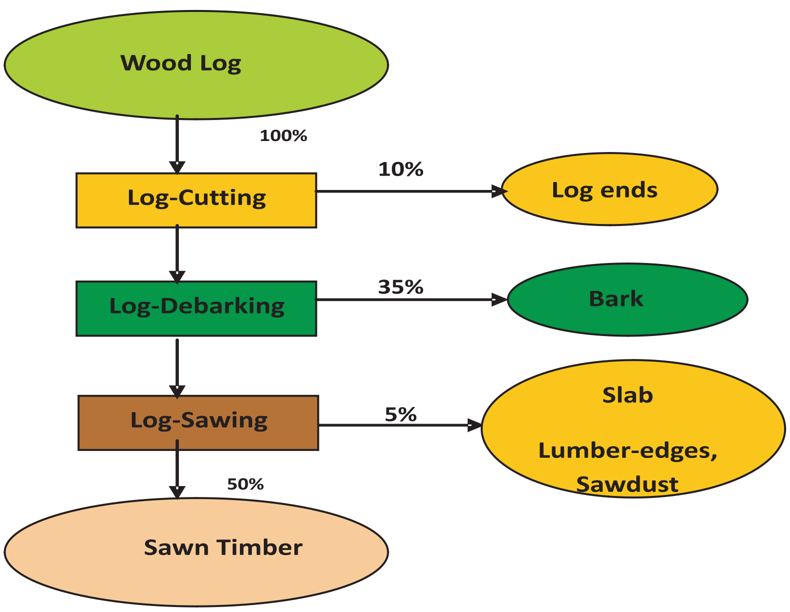



**Figure 5:** Mass balance of wood processing at Sawmill [27]

**Figure 6:** Rice Husk Dump Site at the Abakaliki Rice Mill Cluster

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## Acknowledgements

The authors gratefully acknowledge the funding received from the United Nations Industrial Development Organization (UNIDO) to conduct the study. Also acknowledged is the contribution in kind received from the Nigeria Office of the United Nations High Commission for Refugees (UNHCR). The role played by the Justice, Peace and Development Commission (JPDC) of the Catholic Diocese, Ijebu-Ode in gathering data for the study is gratefully acknowledged. Mention must be made of the assistance received from Mrs Rita Ossai, Mrs Felicia Yewande Ogunbanke and Mr Lawrence Yegwa to ensure the success of the exercise. All your collective efforts to the authors during the course of the study are gratefully acknowledged.

# Engaging Renewable Energy in Nigeria: The low Hanging Fruits – Part 1 Solar Water Heaters (SWHs) and Solar PV

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## ABSTRACT

Renewable Energy (RE) has been in the consciousness of some segments of the Nigeria public in the past decade at least, while it has been in the academic and research institutes fora since the 1970s. It is well enunciated in the National Energy Policy of August 2003 and in the Draft National Energy Master Plan of June 2007, while it is the main focus of the Draft Renewable Energy Master Plan of November 2005. Nevertheless, RE is yet to make any noticeable impact on either the life of the ordinary Nigerian or even the national energy mix, save for biomass (mostly fuel wood with little or no value-added save for charcoal) consumption predominantly by the household/domestic sector. This paper considers the barriers to the uptake of RE in Nigeria and offers the experience (some personal) of other countries (some in Africa) who have successfully engaged RE into their energy mix with the three-fold benefits of energy security, low-carbon jobs creation, cleaner environment from reduced GHG emissions through identifying the low hanging fruit RE sources in treading the Low Carbon Development path to sustainable growth. Key R&D areas, issues of Standards and Specifications are highlighted as necessary in each part of the 5-part paper. The 5-part paper is as follows:

- Part I – Solar Water Heating Technologies;
- Part II – Other Solar Thermal Technologies and Energy Efficiency & Management;
- Part III – Solar PV Technologies;
- Part IV – Biomass and Biofuel Technologies;
- Part V – Small Hydro and Wind Power Technologies;
- Part VI – Policies – those which may, and those which cannot work in Nigeria.

## 1.0 INTRODUCTION

That solar thermal energy is the lowest hanging fruit any nation should readily engage is not in any doubt from Figs. 1a and 1b from the 2010 Edition of IEA Solar Heat Worldwide – Markets and Contribution to Energy Supply 2008*[13]*. Fig. 1a depicts the phenomenal growth in installed capacity of flat-plate and evacuated tube collectors worldwide from 2000 to 2008 with an average annual growth rate of 20.1%, and China consistently having the lion shares throughout the period. Between 2007 and 2008, considerably high worldwide growth rate of 37.1% was achieved, with the following regions contributing the indicated growth rates: Europe (+62.5%), USA and Canada (+41.8%), Australia and New Zealand (+39.7%), China (+38.4%) and Japan (+21.9%). The total solar water collector installed capacity in 2008 has been reported to be 132 GWth by IEA *[12]* and 142 GWth by REN21 – Renewable Energy Policy Networks for the 21st Century *[9]*.

The annually installed capacity of flat-plate and evacuated tube collectors in $kW_{th}$ per 1000 inhabitants in 2000-2008 appears in Fig 1b where the dominance of the Middle East (Israel and Jordan) in 2005-2008 and China throughout the period is apparent. The modest but consistent growth rates recorded by Australia and New Zealand and by Europe is noteworthy. The African continent's insignificant growth rate is noteworthy, with only Namibia, South Africa, Zimbabwe and Tunisia being the four major countries on the continent striving to keep abreast of SWH worldwide market trend.

In terms of the contribution to the energy supply and $CO_2$ reduction, in 2008, both flat-plate and evacuated tube collectors had a total capacity of 131.8 $GW_{th}$ while the installed capacity unglazed plastic collectors used mainly for heating swimming pools was 18.9 $Gw_{th}$.

Table 1 gives details on solar thermal collectors in four African countries and eight other countries from the list of 53 countries in the list of the IEA book *[13]*. The four African countries are the only African countries in the list of 53 countries worldwide in the IEA study. The tables tabulate the following in each of the countries in 2008: total collector area, $m^2$; total installed capacity, $MW_{th}$; calculated number of systems; annual collector yield in GWh/a & TJ/a; annual fossil energy savings displaced by the use of solar thermal energy, toe/a; and the annual reduction in tonnes of $CO_2$ emission from the fossil energy saved. Table 1 relates to all solar thermal systems for hot water heating, space heating and swimming pool heating installed worldwide at end of 2008 while Table 2 is for solar thermal systems using flat-plate and evaluated tube collectors (e.g. for hot water and space heating and low temperature industrial process heat).

In Table 1, the annual total collector yield globally from the 53 countries in 2008 was calculated by IEA at 109,713 GWh (394,968 TJ), corresponding to 12.4 mtoe energy savings and a carbon emission avoidance of 39.4 $mtCO_2$ out of which China's share was 57.3% and 57.4% respectively. For collector surface area installed in 2008, 16 countries in the IEA report had more than 1million $m^2$; nine had more than 2million $m^2$; nine had more than 3million $m^2$; four had more than 5million $m^2$; only China, Germany and Turkey had more than 10illion $m^2$; while China was the only country with more than 100million $m^2$ collector surface area installed.

On the other hand, Table 2 excludes unglazed solar thermal collectors used primarily in swimming pool heating and focuses more on hot water and space heating as well as industrial process heating applications. Comparing Tables 1 and 2, it is seen that solar thermal heaters of most of the countries listed in the tables are of the flat-plate type and/or evacuated tube collector type as the two entries are the same in such cases. However, for Brazil, Germany, USA, India, Israel and South Africa, the differences in the entries in the two tables result from the exclusion of solar hot water heaters of the unglazed flat plate type mainly used in swimming pools in Table 2 and which are significantly used in these countries.

Table 2. Calculated annual collector yield and corresponding oil equivalent as well as $CO_2$ reduction of solar thermal systems using flat-plate and evacuated tube collectors (e.g. hot water heating and space heating, low temperature industrial process heat) installed by the end of 2008 in twelve selected countries. *[13]*.

The share of solar water heater capacity among the top 10 countries/regions of the world in 2007 appears in Fig. 2a and 2b. China had 66.7% of the world market in 2007 which had been slightly reduced to 66.4% by 2008. The remarkable 80.2% addition of solar water heating capacity in China between 2007 and 2008 shown in Fig 2b is outstandingly phenomenal, where other countries and regions of the world are in single digit percentages.

Investment flows in 2008 invested in renewable energy worldwide was an estimated US$120 billion, including new capacity and biofuels refineries. Solar hot water collector investment share of this was 6% (i.e. US$7.2 billion) *[9]*. The US$120 billion amount in 2008 was up from about one-quarter of this amount four years earlier in 2004. Solar hot water collectors grew 15% worldwide in this period. *[13]*. Development assistance for renewable energy in developing countries also reached about US$2 billion in 2008.

## 2.0 INVESTMENT FLOWS IN SOLAR THERMAL ENERGY, JOB CREATION, ENVIRONMENT AND ENERGY SECURITY.

The direct connection between the above investment flows and jobs and employment creation is relatively obvious. The IEA estimates that the solar heating and cooling sector employs more than 200,000 people worldwide *[6]*. Other sources give much higher estimates of solar heating and cooling jobs.

Nigeria with most of Africa is left out of this investment flow with its resultant positive effects on jobs and employment creation, environment and energy security. Yet there is much sunnier climate in Nigeria and all of Africa than in Europe which is at the forefront of solar water collectors for domestic, commercial and industrial applications. The energy savings as well as the $CO_2$ emission reduction in Tables 1 and 2 amount to cleaner environment, laudable global warming mitigation effort while also moving in the desirable direction of low carbon and sustainable growth.

It might not be so obvious to the casual reader that considerable fossil energy savings can accrue to Nigeria if we are ready to apply some of the regulatory and fiscal measures that have been successfully engaged in the success stories in Tables 1 and 2. Such fossil energy might be from our thermal power stations which contribute about 70% of the total grid electrical power which constantly fluctuate between 1,500 and 3,500 MW as we all know well. On the other hand it could be from the kerosene or the fuel wood and charcoal used in cooking in the average Nigerian home; or it could be from the cooking gas in the more affluent home kitchens; in hotels, government institutions such as teaching hospitals, armed forces barracks, etc. In the private sector, it could be from low temperature (< $90^oC$) industrial process heat in such operations requiring drying, malting, etc.

A small desk study was conducted recently to estimate the amount of fossil energy (electricity, kerosene, LPG, fuel oil, etc) used to produce hot water in hotels, teaching hospitals, institutions, some homes, etc., *[3]*. The study is based on an electric water heater (geyser) of 1 kW power rating, say in a hotel bathroom operating for 5 hours a day. We remember that even our electric pressing iron is normally rated a bit more than this, thus the above heater rating is modest. We also know most of them are left on all day, 24/7, thus our 5 hours daily is another modest assumption. Let us now base our calculation on 1 million of such water heaters nationwide, and we will obtain 5000 MWh/day energy consumed daily by the heaters. In a year this will be 1,825,000 MWh/yr. This is about the energy production of a 425 MW power plant (could be a 5 X 85 MW or a 10 X 42.5 MW steam or gas turbine power station) working at 75% plant factor with 65% overall efficiency at rated power full blast throughout the year!

The above 425 MW power plant will produce about 2 million tonnes of $CO_2$ annually (1.92 to be exact), which would be saved our environment if solar water heaters had been used to achieve the purpose. From the thermodynamic point of view, using such a power plant to produce heat from resistive heating is using a high grade electrical energy to produce a lower grade thermal energy, much like Nigeria has been doing for decades using high grade chemical energy in natural gas to produce unwanted heat energy in the Niger Delta environment!

Before leaving this subject, using solar water heating will also qualify for registration consideration of 1,825,000 Certified Emission Reduction (CERs) units annually under the Clean Development Mechanism of the UNFCCC which could be traded at the prevailing rate on the international carbon market. A CER now sells for about Euro 20 to 25. A CER is equivalent to 1000 tonnes of $CO_2$ and CER emission certificates are issued upon laid down verification procedures of the UNFCCC.

## 3.0 WHY NIGERIA HAS NOT MADE MUCH PROGRESS ON ENGAGING SOLAR THERMAL ENERGY

Chapter 3 of the Renewable Energy Master Plan (REMP) of 2005 *[11]* funded by the UNDP for the Nigerian government is on Targets [Short (2007), Medium (2015) and Long Term (2025)] deemed critical to the achievement of the vision of the REMP. Section 3.3 is devoted to Renewable Non-Electricity Targets for energy production from solar thermal, biomass and biogas. Solar thermal share of total thermal energy are 10%, 20% and 40% in the S, M and L terms, made up of solar water and (industrial) air heating of 14,534.2 GWh, 28,297.9 GWh, and 59,728.6 GWh respectively. Furthermore, the implications of these amounts of solar thermal energy are spelt out in Table 3.4.1 where 4000, 57,100 and 146,600 solar water heating collectors are envisaged for the S, M and L terms. In Table 3.4.7, the number of solar water heating collectors with a 2m$^2$ surface area in the long term is indicated as 1,146,600.

Chapter 4 of REMP on Planned Activities and Milestones details six national programmes on renewable energy including one specifically for its promotion nationwide. Project Concept Notes are included in the Annex among which is the National Solar Heating Programme (NASHP) slated for 2005 – 2025, and with the following stated objective: "*To replace a significant fraction of low temperature (< 80°C) heating applications in the domestic, commercial, institutional and industrial sectors with solar energy, thereby resulting in thousands of tonnes of avoided $CO_2$ into the environment while releasing fossil fuels and biomass that would otherwise have been used for more useful work*".

Planned activities to achieve the outcomes are given on page 187 of REMP as follows:

- Enact the National Solar Heating Obligation ordinance or bill at the Local, State, and National Assemblies for solar water heaters on all new buildings (commercial, government, hospitals, clinics, & institutions);
- Provide attractive fiscal market incentives for the adoption of solar heaters in the domestic, commercial, and industrial sectors through specific Solar Thermal market Incentive Programme (STMIP);
- Standards Organization of Nigeria (SON), together with other stakeholders such as the building industry and relevant professional bodies, to develop Codes of Practice and Codes of Conduct/Ethics for manufacturers and vendors;
- Performance & technical Standards for solar water and air heaters, solar dryers, solar cookers, solar stills, etc.;
- Minimum Specifications to be met for solar thermal products for the Nigerian market
- Testing procedures, certification scheme, product quality and safety assurance criteria, compliance strategy, standards enforcement and corrective, implementable sanctions;
- Product standardization methodology for the Nigerian solar thermal energy industry; and
- Training and certification programmes for artisans, technicians, engineers, business community, banking community, public sector officials, etc. on solar thermal technologies through national energy centres and other higher institutions and NGOs as soon as possible within the year 2005.

In the 2007 National Energy Databank, a Compendium of Renewable Energy Systems in Nigeria by the Energy Commission of Nigeria *[6]*, there is only one project listed on solar water heating, the Solar Water Heating Project at UDU Teaching Hospital in Sokoto. Most probably, just this one still exists today in the whole of Nigeria! This is a 1000-litre capacity system which at best would be of no more than 10 m$^2$ surface area. This would work out at 0.0000714 m$^2$ installed capacity per 1000 Nigerians. Compare this with Egypt with population of 81.5 million (2008 World Bank, WDI) which by 2000 had about 200,000 households using DSWH systems with an estimated 400,000 m$^2$ collector surface area! This works out at 4.9 m$^2$ per 1000 Egyptians.

With all above, why have we not seen any desired visible movement on solar thermal energy uptake? The answer lies mainly with the legislative branch which needs to be sufficiently educated on the desirability of enacting the relevant Bills/Acts/Laws to encourage the private sector to enter the turf and spur market development. Government on its part will need to show concern for national economic development through well-funded, properly conceived national programmes as expounded above with attractive incentives aimed at the various sectors. None of these has happened so far, six years down REMP. Other successful nations in renewable energy engagement have taken this last but very critical step seriously and they are reaping the benefit today as we have seen in Tables 1 and 2. We will presently look at a number of case studies from successful countries in Tables 1 and 2 to see what we can learn from their experiences, after considering some typical SWH collector system costs worldwide.

## 4.0 TYPICAL SYSTEM COMPARATIVE COSTS

Table 3 is indicative of typical costs of domestic solar water heaters (DSWH) in selected localities worldwide. Among determinants of cost of solar water heater (SWH) systems are system and installation complexity or simplicity, labour costs, amount of locally manufactured parts in the system, competitiveness of the local market, etc. Domestic SWH systems are basically of three types: (i) Flat-plate collector, consisting of an insulated box housing the blackened absorber plate made of metal or polymer and covered on top with one or more glass plates; (ii) the integral collector-storage system (ICS) consisting of one or more black tanks or tubes in an insulated, glazed box; and (iii) evacuated tube solar collectors featuring rows of glass tubes with metal absorber finned tubes.

<u>Notes:</u> *The thermosyphon systems are one family systems with 2.4 $m^2$ collector and 150 litre storage tank. The pumped system has a 4-6 $m^2$ collector and 300-litre storage tank. DSWH systems in Europe cost EUR50-160/MWh of heat energy which is competitive with retail electricity prices but more expensive than heat from natural gas. The Combi-systems for combined space and water heating cost about EUR160-500/MWh. These costs are projected to significantly decline in the long term.[Ref. 10]*

Active solar water heater systems may either be the direct circulation systems which use a pump to move the water through the collector into the end-use point or the indirect circulation system having a closed circuit anti-freeze dozed water exchanging heat inside a heat exchanger with the water required in the end-use point. Passive solar water heater systems on the other hand are much simpler hence less expensive and likely to be more durable systems than the active systems. Passive systems are also of two types: the ICS and the thermosyphon systems. Solar water heaters normally available with an electrical or gas heating element as a backup for cloudy days or for when demand exceeds design conditions.

It should therefore be no surprise to find widely varying solar water heater cost structure as in Table 3. Even then, the installed cost shown above tends to indicate that indeed, solar water heating is one of the lowest hanging fruit technologies any serious nation blessed by nature with reasonable solar energy resource would readily exploit. This is why it has been ranked highest in the order of presentation of the subsequent range of renewable energy technologies.

## 5.0 LESSONS FROM ISRAEL, GREECE AND BARCELONA, SPAIN ON SOLAR WATER HEATERS

The two main promotion mechanisms adopted by countries worldwide for renewable energy are economic promotion mechanisms and regulatory promotion mechanisms. The latter was pioneered by Israel when in 1980 the Israeli Knesset passed a law requiring the installation of SWHs in all new homes (except high towers with insufficient roof area) applicable throughout Israel. Israel today is reputed to be the world leader in per capita solar energy utilization, and 85% of Israel's 1,650,000 households are reputed to use SWHs. This annually saves Israel 1.6 billion kWh of electricity and represents 21% of her domestic electricity consumption *[1]*.

Greece began her own SWH encounter in the 1970s when the first DSWH collectors were imported from Israel and the first industrial units for the production of 2.5 $m^2$ DSWH systems were established. Thirty years later, by 2001, Greece had become the leader in Europe in $m^2$ DSWH installed per capita and the second place (after Israel) globally *[2]*. Reasons for such success adduced in the REACT Case Study *[2]* are:

- Economic/Fiscal Incentive through a tax exemption scheme introduced in the 1980s for DSWH systems;
- Reliable technology and lack of bad examples in the installation of the first systems. To prove the product reliability, it is necessary to define the minimum standards to be attained by such products; and
- Marketing strategy which aimed mainly at the convenience of having "free" hot water on demand, which was possible most of the year given Greece's large solar energy potential.

The study noted that the low price of electricity which was, and still is, the main alternative for domestic hot water production in Greece, was a major barrier. It also stressed the fact that the "reputation" of the product was of great importance in developing the industry as bad examples to kill the market were lacking. The systems, which had an electric heating element backup, were covered by a 5-year guarantee, which is about the payback period.

Furthermore, the tax incentive policy implementation was kept simple and straightforward, not requiring any special management overheads. The buyer simply had to submit his receipt with their tax form and the amount would be deducted from the total family income, representing tax deductible with a cap of 40% of the cost. Thus, this was an indirect subsidy without creating any complex bureaucratic schemes as would be required for the management of a direct subsidy programme.

The public power corporation (PPC), participated actively in the promotion by distributing a small information leaflet along with the utility bills of their customers on behalf of the Greek Solar Industry Association (EBHE). The steady growth pattern of number of DSWH systems installed in Greece between 1980 and 2001 is shown below in Fig. X. By 2001, the DSWH collector surface area was 3 million $m^2$ in this graph, and from Table 1 had further increased to 3,870,000 $m^2$ by 2008.

**BARCELONA, SPAIN**

GTZ did a recent study on the promotion of Renewable Energies, within which was a section on International Experiences with the Promotion of Solar Water Heaters at Household Level *[12]*. Two contrasting examples in this study will be considered in this section, namely, Barcelona, Spain and Tunisia. The City Council of Barcelona, the capital city of Catalonia region of Spain in July 1999 approved the Barcelona-Ordinance (or law) (Ordenanza Solar Termica de Barcelona) which came into force in August 2000, and it requires all new buildings with a daily average energy consumption of hot water supply exceeding 292 MJ (approximately 2000 litres heater capacity) to generate at least 60% of the required heating energy from solar water heaters. This would be equivalent to any of the present day 774 Nigerian Local Government Councils coming out with a law seeking to benefit Nigeria in 2025!.

At that time in 1999, this was only the second such law coming after that of Israel in 1980, but it was the first such Ordinance in Europe. Also, at the time, Barcelona's energy mix was predominantly nuclear, with 4% from hydro power and only 1% from renewable energy sources, hence it would have eminently qualified as a green city. Nevertheless, the forward looking city energy agency at the time forecast about 30% increase in both the city energy consumption and $CO_2$ emission by 2010, leading the City Council to action on the law, convinced of the extremely favourable solar energy potential of Catalonia, with average of 2,477 hours of sunshine per year and annual solar radiation of 1,502 $kWh/m^2$, compared with Nigeria's average annual 2,400

sunshine hours and 1,825 kWh/$m^2$ solar radiation, a bit lower at the coastal zones and much higher at the northern Sahelian zones).
The Barcelona-Ordinance aimed to install 90,000 $m^2$ new (relative to 1990) solar water heater collector surface area by 2010 (i.e. by the end of this year, a goal set in 1990 by progressive, result-oriented local politicians!!!). Between January 1st 2000 when it came into effect and March 2004, Barcelona had achieved an increase of installed SWH collector area from 1,650 m2 to 24,531 m2 representing 3,415 tonnes per year of $CO_2$ emission saved the environment.

The Ordinance is a legal mechanism, without any economic or financial incentive involved, just as was the case of Israel in 1980. The Ordinance further required all swimming pools to be heating to be sources 100% from solar energy. The Ordinance installation obligation covers all residential buildings, hospitals, gymnasiums, and commercial buildings, and was thus deliberatively selective to limit massive resistance of the general public. With the 292 MJ daily threshold energy consumption for water heating in the Ordinance, most small residential homes were excluded since such energy consumption would apply only to residential apartment complexes of about 20 units with 4 to 5 person-occupancy in each unit. The procedure was basically simple; the owner or builder would only need to prove when applying for the building permit how the water heating energy demand of the proposed building is to be met in regard to the Ordinance. Further, he would be required to ensure and undertake that the solar heating system is actually used and properly maintained and repaired as necessary before the building permit is issued.

The City Council ensured mass participation and buy-in, as many stakeholders from professional bodies and builders, renewable energy associations, municipal representatives, etc. participated in the design and dissemination of the Information dissemination strategies which also included a Guidebook explaining the Ordinance and how it affects the people.

Quality assurance was also carefully planned. A number of qualified institutions were authorized to certify the SWH collectors to be used in each building design while the installers and technicians must be registered with their relevant professional bodies and additionally posses a certificate on the vocational training required to qualify as an installer of SWHs.

The results of the Barcelona-Ordinance have been spectacular and copied by municipalities not only in Spain but all over Europe. As at 2005, about 40% of all new buildings possessed a SWH. About 65% of the systems were used in the residential sector, 12% in gymnasiums, and 11% in hotels according to a survey by the Barcelona city energy agency.

**TUNISIA, NORTH AFRICA**

According to the GTZ report *[12]*, participating banks grant loans to the SWH manufacturers who in turn transfer these loans to households in the SWH scheme by selling their systems directly to such households, offering them the financing facility. Monthly repayment is effected through the monthly electricity bill of STEG over a period of 5 years, reducing the risk of default. The energy savings ideally cover the monthly rates fully so that the household would not pay a higher invoice amount than what they were paying before the loan. STEG collects the monthly payments which it lodges with the participating bank which in turn shares it among the credit-allocating banks. The interest rate is slightly below the going market rate, fixed at 7% at the beginning of the programme in March 2005. This interest rate is gradually reduced over time to zero at which point the interest subsidy would have been totally eliminated from the programme, making it a subsidy-free loan market.

The promotion programme is limited to private households only, and only a limited number of producers are allowed to participate. The total funding for the programme is US$ 2 million provided by the Italian Ministry of

Environment and Territory, half of which is used by UNEP for interest subsidy and the remaining half by the public sector energy department ANME as capital cost subsidy.

Publicity and information dissemination on TV and radio as well as the print media was well coordinated, including promotional posters and leaflets located strategically at banking halls, government buildings, etc. and coordinated by both UNEP/DTIE and ANME.

ANME is responsible for quality assurance, quality verification, technical standards, installation and installer certification as well as technical training of the SWH installers.

UNEP/DTIE expectation is that up to 30,000 households would benefit from PROSOL financing by the end of the programme. By 2011, a total SWH collector area of 220,000 $m^2$ is expected to be installed and financially supported by the promotion programme. Furthermore, it is assumed that each US$ subsidy would be able to generate about US$ 5 to 6 of additional credit volume.

**SPAIN (ESPANA)**

In 2006, Spain became the second country in the world after Israel to mandate the installation of solar water heating systems, at which time the share of RES heating and cooling in the gross electricity production was 3.6%. The solar thermal installed capacity had reached 1,199,745 MW in 2007. On 17th March 2006, the Spanish government approved the new Technical Buildings Code (CTE, Codigo Tecnico de la Edificacion), the most significant reform of the Spanish building sector for decades. The CET built on the success of the previous municipal solar ordinances, such as those of Barcelona, Madrid, etc. The CET includes the following main areas: security of the buildings structure, other safety and health issues, sustainability and energy efficiency of the buildings. The latter part"Documento Basico HE – Ahorro de Energia") goes far beyond the minimal level of implementation of the EC Directive on Energy Performance of Buildings and includes an obligation to cover 30-70% of the Domestic Hot Water (DHW) demand with solar thermal energy. The solar thermal part applies to all new buildings and to those undergoing a renovation. It applies to any kind of buildings, regardless of their use.

Spanish municipalities have been adopting such measures since 2006 in order to foster the implementation of RES technologies in new as well as old refurbished buildings. More than 60 bylaws exist in Spain, affecting more than 20% of the population.

## 6.0 RENEWABLE ENERGY PROJECT LOAN PROGRAMME

This national programme entered into force in 2008 and is aimed at giving 100% finance contribution on the investment costs of, among others, applications of solar thermal facilities with a capacity equal to, or higher than 20 kW, and it covers many legal entities excepting private companies.

## 7.0 RENEWABLE ENERGY PROJECT DEPOSIT PROGRAMME

This is targeted at individuals, SME and micro-companies. The investment in a project on renewable can be paid through a bank deposit ranging from Euro10, 000 to Euro300, 000. The beneficiary has a 2-year period to refund the deposit, with a 7% per year interest rate.

Investment subsidies under the REP 2005-2010 As from 2008, the Renewable Energy Plan (REP) 2005-2010 allocates financial incentives for solar thermal projects. Targeted at individuals, private or public companies, organizations and communities of neighbours, the subsidy covers 37% of the total costs of the project.

## 8.0 CALIFORNIA, USA REBATE PROGRAM, CSI-THERMAL

The California Rebate Program, CSI-Thermal *[8]* is funded by utility ratepayers of four private sector utilities serving about 90% of all

Californians. The program funding of $350 million is divided into two, $250 million to replace natural gas water heaters and $100.8 million to replace electric water heaters. Natural gas users in residential dwellings get a rebate of up to $1,875 while commercial and multifamily buildings get up to $500,000. Electricity users on the other hand get up to $1,250 for residential users and $250,000 for commercial and multifamily buildings. These incentives decrease yearly till they are eliminated altogether.
The CSI-Thermal program arose from the experiences gained from the 2007 Solar Water Heating Pilot Program of the California Center for Sustainable Energy (CCSE). Four main barriers were then identified to the public acceptance of solar water heaters, which should be kept in mind by any developer of new programs.

The goal of CSI-Thermal is to offset 585 million therms by 2018 which implies installing DSWH in 200,000 single-family dwellings that use natural gas (i.e. 90% of Californians), and to offset 275 million kWh electrical energy which implies installation of DSWH in 100,000 homes that use electricity to heat water.

## 9.0 CONCLUSIONS

### WHAT IS THE WAY FORWARD FOR NIGERIA FROM THE 10 m$^2$ SWH COLLECTOR AREA?

From the above case studies, it is clear that Nigeria would need to wake up from the deep slumber of 10 m$^2$ solar water heater collector surface area for our 140 million population. It would be embarrassing and shameful to have it listed among other countries in Tables 1 and 2.

There is therefore an urgent need for a Solar Water Heating Law to be enacted by the National Assembly which will be applicable to all new buildings in the residential, commercial sector, hotels, public sector institutions, teaching hospitals, and in the industrial sector nationwide. The law should also include the retrofit of old buildings in these sectors.

Government on its part must follow this up with well articulated national pilot and market development programmes on solar thermal energy for low temperature (< 90$^o$C) heating applications in various sectors of the economy, particularly in the residential, commercial, and industrial sectors. Sectoral total energy demand in Nigeria from the National Energy Masterplan of June 2007 *[7]* indicates that the household sector has the largest demand forecast for 2010 at 21.65 Mtoe (42.5%), followed by Transport at 13.62 Mtoe (26.8%), Industry 7.81 Mtoe (15.4%), and Services 7.74 Mtoe (15.3%). Of this large amount of energy consumed in the domestic sector, 40-50% will easily go into heating water, either for bathing or as precursor to cooking, which can conveniently and more desirably be supplied by solar water heaters, instead of the current electricity, LPG, fuel wood, and charcoal.
The suggested initial promotion is for the relatively low-cost DSWH thermosyphon systems costing between the EUR 200 (of China) and the EUR 700-900 (of Europe) at the domestic level and the larger Combi-systems and evacuated tube collectors for commercial and industrial large-scale applications, e.g. hotels, teaching hospitals, institutions, public buildings, armed forces and police barracks, etc.

Economic/financial/fiscal incentive measures are recommended for all the sectors, especially the residential sector. As the market develops, the more expensive pumped systems can be gradually introduced into the household sector market. It must be noted that Nigeria's poor infrastructural woes includes lack of public piped water services and this might restrict such pumped systems to homes with piped running water and grid electricity for pumping water through the system. The good news on SWH collectors is that even in rural areas without piped running water or electricity services, batch-type SWH thermosyphon systems can be used.

The initial promotion of the pumped systems however would be more successful if targeted at the large commercial/industrial/tourism cities of Lagos, Abuja, Port Harcourt, Calabar, and Warri, and the high altitude States, e.g. Plateau, Adamawa, Taraba, Nassarawa, and Benue.

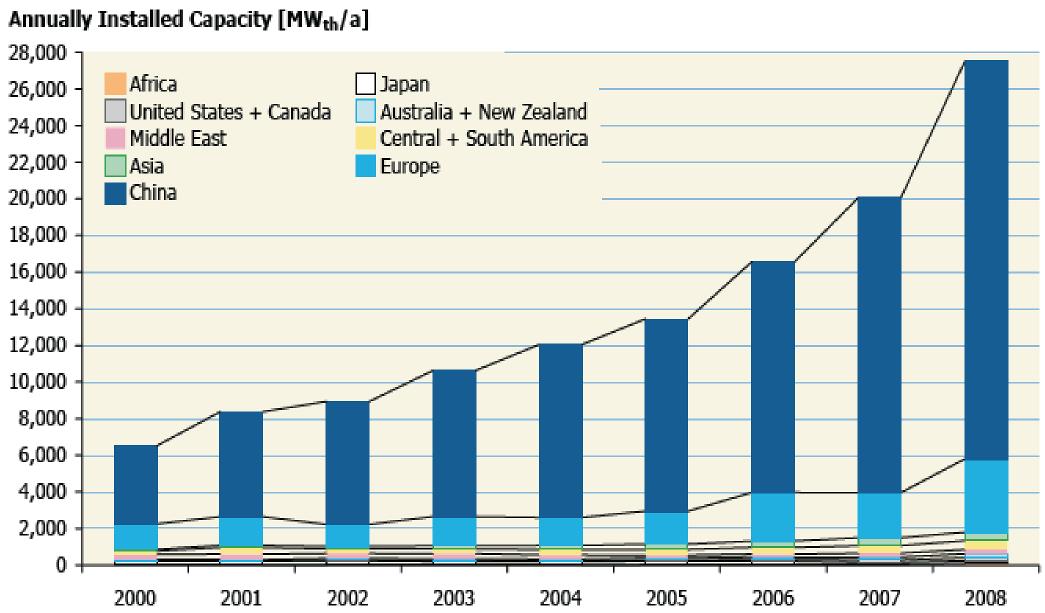
Issues of system reliability, codes and standards, installation as well as installer certification will also need to be well coordinated between the Energy Commission of Nigeria ECN, the Standards Organization of Nigeria (SON), the professional bodies in engineering, architecture, and building, and the SWH manufacturers/vendors to block the influx of sub-standard equipment and unqualified practitioners in the field services. SWH installation requires technical competence of the installers and equipment manufacturers/suppliers. They must be specially trained and certified to be allowed into the profession; otherwise we risk market failure from ruined technology reputation from either substandard systems or ill-prepared installers.

Finally, we recall that Israel and Barcelona are today reaping the fruits of seeds sown by their foresighted lawmakers and leaders 30 and 20 years ago, respectively. We also need to start purposeful development someday, even if it is in only one or two areas of comparative advantage. The Energy Commission of Nigeria must find a way to make the Energy Committee of the National Assembly understand what is at stake here, otherwise, it will be equally culpable when future generations start to ask questions on why this vast clean natural energy potential has continued to be wasted for so long, while lesser endowed countries are using it, and creating jobs for their people from exporting technologies based on it. Responsible political leaders worldwide seek to provide for their future generations, and would not selfishly squander nature's gift in their own generation. This should be the message of the Energy Commission to all tiers of government.

| Barrier identified | Remedial Action taken in CSI- |
|---|---|
| Inadequate consumer education | Large marketing & PR budget for public education |
| Few highly skilled solar water installers | Devotion of some marketing outreach funds for training; CCSE partnership with community colleges to develop |
| Solar water heater projects need to satisfy relevant building Codes | CCSE developed educational opportunities for building inspectors to make them understand solar water heater |
| High upfront solar water heater costs are decidedly a disincentive to its uptake | Floating of the California Rebate Program, CSI-Thermal in response. The \$6,000-\$7,000 average system cost can be cut in half |

As shown in Table 4: Barriers against Solar Water Heating System

Analyzing the market development of glazed water collectors, from 2000 to 2008, it can be seen that the market of flat-plate and evacuated tube collectors grew significantly during this time period (see Figure 17).



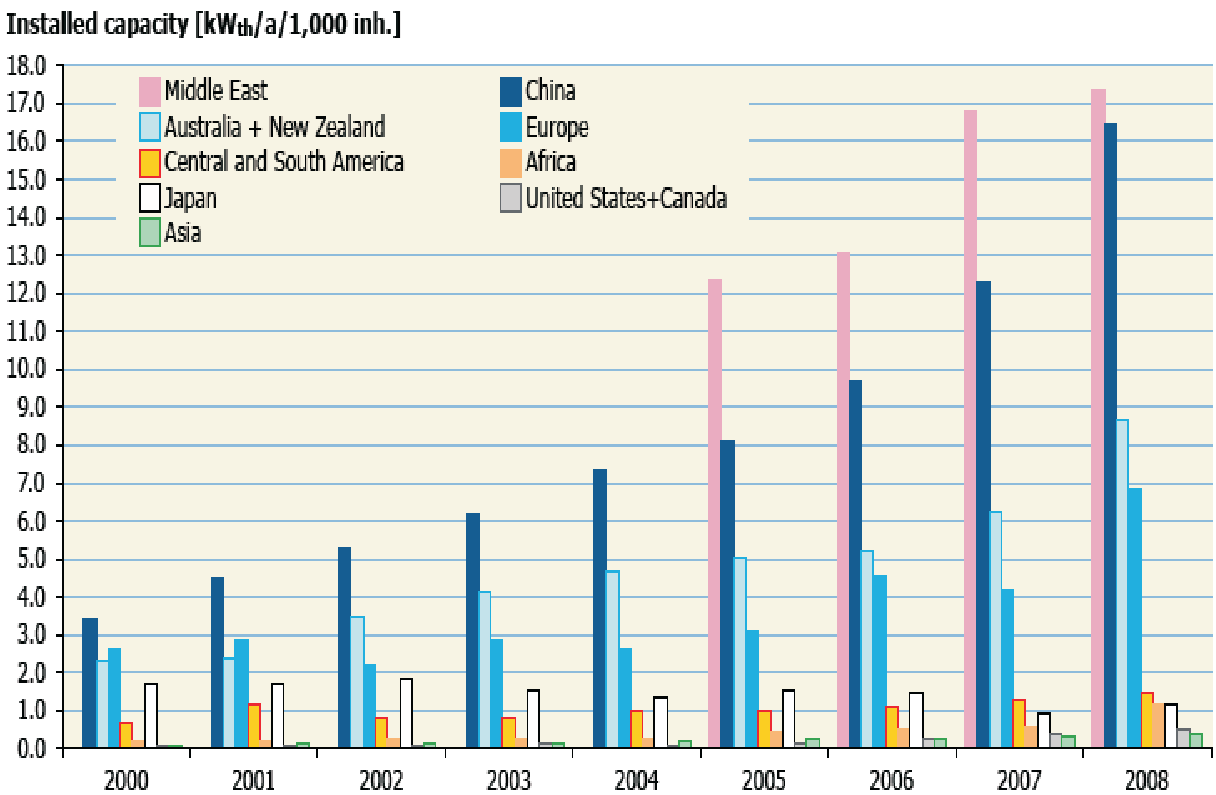

| | |
|---|---|
| Middle East: | Israel, Jordan |
| Africa: | Namibia, South Africa, Tunisia, Zimbabwe |
| Central & South America: | Barbados, Brazil, Chile, Mexico, Uruguay |
| Asia: | India, South Korea, Taiwan, Thailand |
| Europe: | EU 27, Albania, Macedonia, Norway, Overseas Dep. of France, Switzerland, Turkey |

**Figure 17:** Annual installed capacity of flat-plate and evacuated tube collectors from 2000 to 2008

The annually installed glazed water collector area worldwide in 2008 was more than 4 times higher than in the year 2000, and doubled between 2005 and 2008. The worldwide average annual growth rate between 2000 and 2008 was 20.1%.

Compared to the year 2007, the worldwide market for glazed water collectors grew by 37.1%. Especially high growth rates occurred in Europe (+ 62.5%), the United States and Canada (+ 41.8%), Australia and New Zealand

Fig. 1a Annual installed capacity of flat-plate and evacuated tube collectors, 2000-2008. *[13]*.




| | |
|---|---|
| Middle East: | Israel, Jordan |
| Africa: | Namibia, South Africa, Tunisia, Zimbabwe |
| Central & South America: | Barbados, Brazil, Chile, Mexico, Uruguay |
| Asia: | India, South Korea, Taiwan, Thailand |
| Europe: | EU 27, Albania, Macedonia, Norway, Overseas Dep. of France, Switzerland, Turkey |

**Figure 18:** Annually installed capacity of flat-plate and evacuated tube collectors in $kW_{th}$ per 1,000 inhabitants from 2000 to 2008 [13]

Besides Israel and Jordan, the Chinese market led in terms of specific collector area installed (capacity/inhabitant), although China loses absolute dominance due to its large population.

Fig.1b. Annually installed capacity of flat-plate and evacuated tube collectors in $kW_{th}$/1000 inhabitants, 2000-2008. *[13]*.

Table 1. Calculated annual collector yield and corresponding toe as well as $CO_2$ reduction of all solar thermal systems (systems for hot water, space heating and swimming pool heating) installed at end of 2008 in twelve selected countries. *[13]*.

| Country | Total Collector Area, m2 | Total Capacity MWth | Calcula-ted No. of systems | Collector yield GWh/a | Collector yield TJ/a | Energy Savings toe/a | tCO2 annual reduction |
|---|---|---|---|---|---|---|---|
| Brazil | 4,293,206 | 3,005.20 | 764,218 | 2,704.40 | 9,735.70 | 298,904 | 946,384 |
| China | 125,000,000 | 87,500 | 28,493,750 | 62,893.80 | 226,417.60 | 7,145,526 | 22,616,779 |
| Cyprus | 803,520 | 563 | 167,614 | 624.40 | 2,248.00 | 69,169 | 218,698 |
| Germany | 11,071,754 | 7,726.70 | 1,397,411 | 3,834.60 | 13,804.50 | 470,477 | 1,489,896 |
| Greece | 3,870,000 | 2,709.00 | 911,946 | 2,536.40 | 9,131.10 | 272,368 | 862,879 |
| India | 2,547,515 | 1,771.80 | 458,146 | 1,941.10 | 6,988.00 | 219,839 | 697,657 |
| Israel | 3,800,000 | 2,659.70 | 925,998 | 3,402.60 | 12,249.30 | 355,354 | 1,125,664 |
| Turkey | 10,636,800 | 7,445.80 | 2,487,948 | 7,880.40 | 28,369.50 | 879,984 | 2,786,683 |
| Namibia | 6,742 | 4.70 | 851 | 5.30 | 19.10 | 658 | 2,082 |
| South Africa | 975,360 | 682.80 | 72,419 | 584.50 | 2,104.30 | 59,754 | 189,154 |
| Tunisia | 286,080 | 200.30 | 69,546 | 227.00 | 817.20 | 24,135 | 76,445 |
| USA | 20,614,290 | 14,316.40 | 542,787 | 8,024.90 | 28,889.60 | 842,893 | 2,670,575 |
| Zimbabwe | 17,316 | 12.10 | 4,329 | 12.10 | 43.70 | 1,770 | 5,628 |

Table 2. Calculated annual collector yield and corresponding oil equivalent as well as $CO_2$ reduction of solar thermal systems using flat-plate and evacuated tube collectors (e.g. hot water heating and space heating, low temperature industrial process heat) installed by the end of 2008 in twelve selected countries. *[13]*.

| Country | Total Collector Area, m2 | Total Capacity MWth | Calcula-ted No. of systems | Collector yield GWh/a | Collector yield TJ/a | Energy Savings toe/a | tCO2 annual reduction |
|---|---|---|---|---|---|---|---|
| Brazil | 3,490,377 | 2,443.30 | 760,204 | 2,443.50 | 8,796.50 | 273,278 | 865,368 |
| China | 125,000,000 | 87,500 | 28,493,750 | 62,893.80 | 226,417.60 | 7,145,526 | 22,616,779 |
| Cyprus | 803,520 | 563 | 167,614 | 624.40 | 2,248.00 | 69,169 | 218,698 |
| Germany | 10,318,154 | 7,222.70 | 1,393,811 | 3,614.20 | 13,010.90 | 448,704 | 1,421,438 |
| Greece | 3,870,000 | 2,709.00 | 911,946 | 2,536.40 | 9,131.10 | 272,368 | 862,879 |
| India | 2,531,195 | 1,771.80 | 458,146 | 1,941.10 | 6,988.00 | 219,839 | 697,657 |
| Israel | 3,772,878 | 2,641.00 | 925,864 | 3,388.40 | 12,198.40 | 353,964 | 1,121,269 |
| Namibia | 6,742 | 4.70 | 851 | 5.30 | 19.10 | 658 | 2,082 |
| South Africa | 275,682 | 193.00 | 68,920 | 252.20 | 908.00 | 27,135 | 85,954 |
| Tunisia | 286,080 | 200.30 | 69,546 | 227.00 | 817.20 | 24,135 | 76,445 |
| USA | 2,724,910 | 1,907.40 | 454,152 | 1,491.70 | 5,370.20 | 202,589 | 641,678 |
| Zimbabwe | 17,316 | 12.10 | 4,329 | 12.10 | 43.70 | 1,770 | 5,628 |

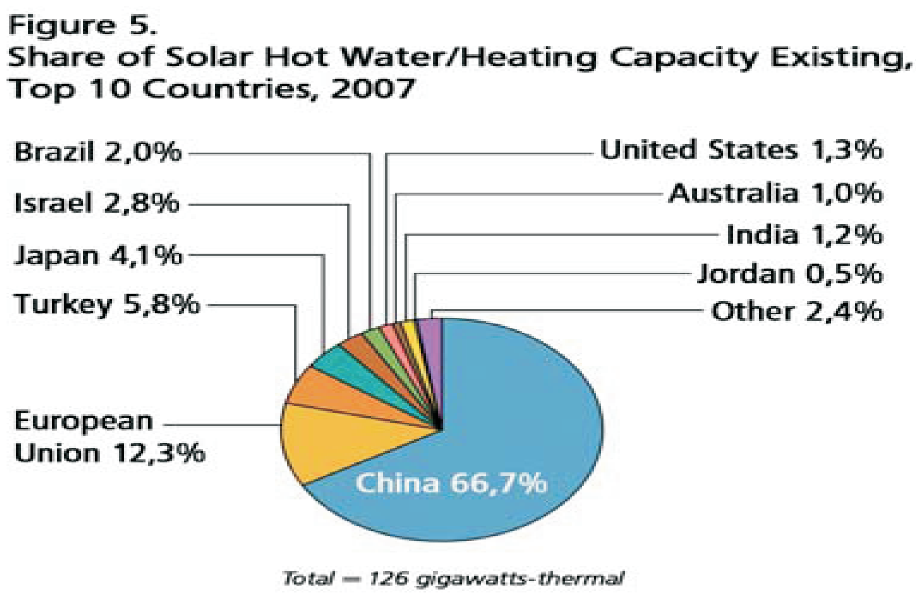



Fig. 2a. Share of 2007 Solar Hot Water/Cooling Capacity for Top 10 Countries/Regions of the World. *[9]*.

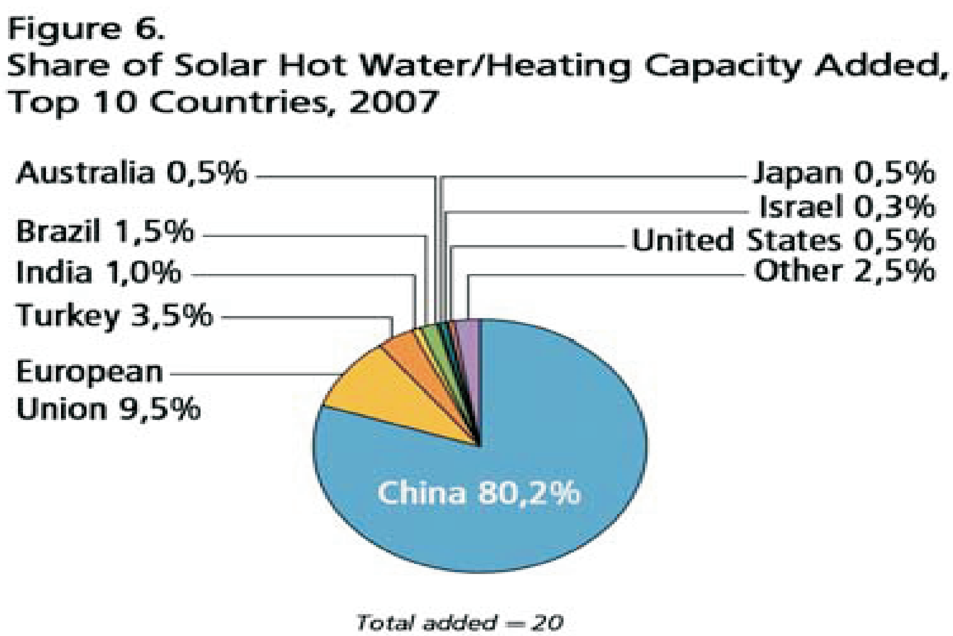



Fig. 2b. Share of Solar Hot Water/Cooling Capacity Added in 2007 for Top 10 Countries/Regions of the World. *[9]*.

Table 3. Typical costs of Domestic Solar Water Heaters (DSWH) in selected localities. *bu - backup*

| State/Country | Type | Cost, Euro (E) or US$ ($) | Life, yrs | Payback, yrs | Ref. |
|---|---|---|---|---|---|
| Barcelona, Spain | DSWH/TS<br>DSWH/PS | E663/m$^2$ ≥E1326 ***for 2m$^2$ system;*** E579/m2 ***for large systems in hotels, apartment bldgs., etc.*** | | | *[12].* |
| Greece | DSWH/TS | E700-900 | **10-15** | 4-6 | *[2]; [10].* |
| China | DSWH/TS | E200 | | | *[10].* |
| Central Europe | DSWH/PS | E4,500 | | | *[10].* |
| Guangdong, South China | DSWH/PS | $4,000-8,000 | | | www.articlekingpro.com |
| California, USA | DSWH/PS | $6,000-7,000 ***But cost halved with tax credit & rebate in Rebate Program*** | | **7-8, EB bu; 13-14, NG bu** | *[8].* |
| Tunisia | DSWH/TS | E260/m$^2$ ≥ E520 ***for 2m$^2$ system in 2005.*** | | | *[12].* |
| Egypt | DSWH/TS | $324-396 ***for150litr*** | | | *[4].* |

*Legend: DSWH – Domestic SWH; TS – Thermosyphon system (i.e. no pumps); PS – Pumped system;*

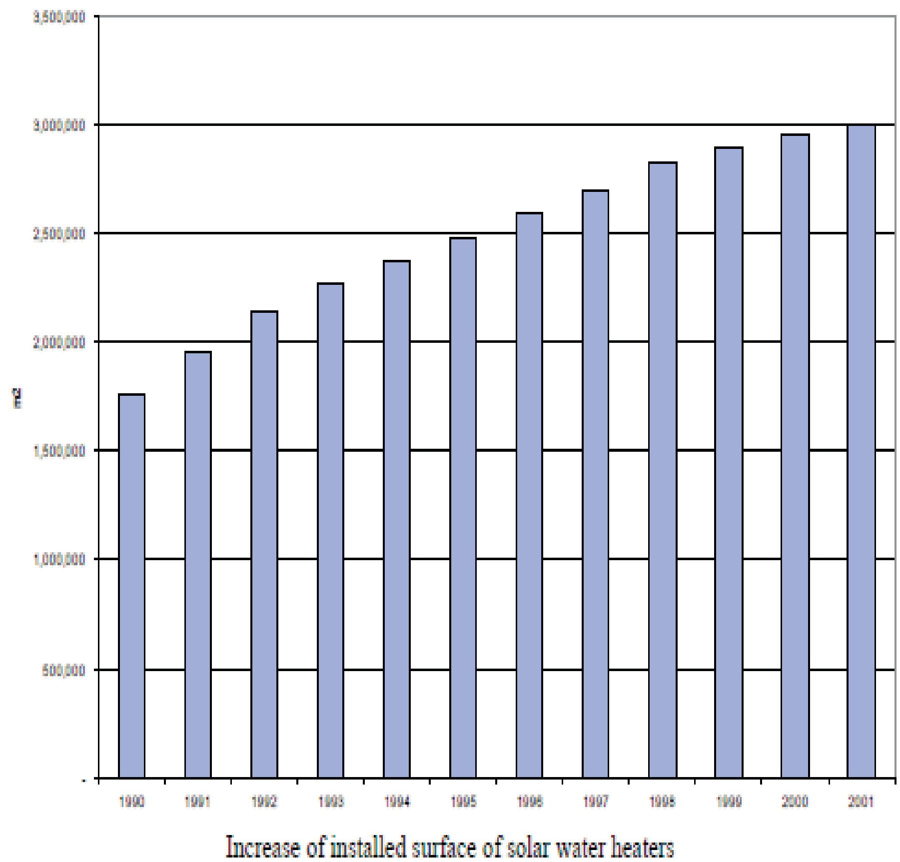



Fig. 4. Growth pattern of DSWH systems installed in Greece between 1980 and 2001. *[2]*.

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# Simulation and Performance Evaluation of a Dual - operated Solar Cooking and Drying System for developing Countries

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## ABSTRACT:

This paper presents performance evaluation of a dual operated passive solar cooking and drying system for an arid and semi arid region. The system has the ability to utilise a range of thermal storage materials including phase change material (PCM) and other locally available oils as the medium for energy storage. The stored energy could be used as a backup to extend the drying and cooking operation of the system during low solar insolation period and night time.

The system has been tested and evaluated in accordance to the figures of merits viz; stagnation temperature test ($F_1$) and water boiling test ($F_2$) for both cooking and drying applications. The system was further tested using different thermal storage materials including water, vegetable oil, wasted engine oil and selected PCM materials for solar cooking and drying applications. The results have shown that, the system could replace most of the current conventional cooking and drying systems in the arid and semi arid climates, and have ability to provide heat retention for up to 5 hours using 4 litres wasted vegetable and engine oils. The heat retention period could practically be further extended when PCM materials are used as a heat storage medium owing to its latent heat storage capability. Computational Fluid Dynamics (CFD) was used for the performance evaluation, the CFD simulation of the dual operated system have shown the optimum outlet duct positions for drying applications. The computated results have shown that dual operation could be best achieved by positioning the duct air outlet at the middle or a bit lower position of the dual operated passive solar drying and cooking system.

**Keywords:** Solar drying, solar cooking, thermal energy storage.

## 1.0 INTRODUCTION

Fuel-wood has been one of the oldest sources of energy known and used by mankind for centuries. Despite the world technological breakthrough and widespread reliance upon fossil fuel among the industrialised nations, fuel-wood has continued to be the dominant cooking energy source used in the developing world. Due to the increasing population in the developing countries, demand for both wood and agricultural land has risen to such an extent that there is now a net depletion of wood resources with a serious consequences such as desertification, soil erosion, food shortage as well as fuel wood shortage. The use of solar cookers is one way of reducing the demand for firewood, coupled with the abandon solar resources in most of these Countries. [Schwarzer et al, (2008)].

In the developing countries more than 80% of the populace lives in the rural areas where up to 90% of the energy being consumed comes from non commercial sources of which fuel-wood is the major energy source. The increasing cost and non availability of conventional energy sources in these areas necessitates exploration of other renewable sources. Fortunately these areas are blessed with abundance solar energy. Passive solar cooking and drying system with thermal heat storage would be an ideal option that would certainly improve the populace's social & economic status, in addition to enormous environmental benefits. According to Michael.et al (2002), Fuel-wood as a dominant energy source for cooking and water heating in the developing world, constitutes to 68%, while animal dung constitutes 13%, Electricity 5%, LPG 1%, Kerosene 2% and Coal constitutes 1% only.

This paper presents the laboratory and CFD simulation evaluation results of a dual-operated passive solar cooking and drying system. The system has the ability to utilise a range of thermal storage materials including phase change material (PCM) and other locally available oils as a medium for energy storage in order to extend its operational period to low solar insolation periods and night

time. This system can store thermal energy inform of sensible or latent heat medium. According to Ahmet Sarı et al (2008); Latent heat thermal energy storage (LHTES) method by phase change material (PCM) is one of the most preferred methods due to its high-storage density and property of storing heat at a constant temperature.
CFD simulation of the model was undertaken in order to asses the effect of the air circulation on the performances of the cooking/drying system. This has been done using the Discrete Ordinance (DO) radiation model in fluent software.

On the other hand Cooking is a reoccurring energy intensive operation used to prepare food for human survival. "The average daily wood consumption in the developing world is 1.3 Kg per person, a family of 5 requires 6.5 kilograms of firewood. [Garba M.M. et al (2008)]

According to Jayaraman et-al (1995), fruits and vegetables losses in developing countries are estimated at 30-40% due to inadequate storage for these perishables food items. The dual operated passive solar cooking and drying system would go a long way in reducing these losses through drying and storing the dried items until the time they are needed.

Similarly, according to 'World Health Organization report, polluted water and sanitation deficiency are the cause of 80% of all the diseases suffered in the developing world. Solar cookers are the only smoke-free solutions mainly for cooking, water distillation and pasteurization.

## 2.0 COMBINED COOKING AND DRYING APPLICATIONS

In different parts of the world, a range of solar cookers were constructed, studied and many were patented. However, their real practical applications is still very limited due to many reasons, such as; unstable climate, single use, economic, cultural, social etc. In order to overcome part of these impediments, a dual operated passive solar cooking and drying system has been developed with thermal energy storage to extend its operation beyond sunshine hours.

The new developed dual operated passive solar system was designed to function as conventional box type solar cooker, and also to operate in its dual capacity as solar drying system. The developed system has an aperture area of 0.40 $m^2$ with a reasonable depth to accommodate a range of cooking pots, and to enable a wide surface area for its solar drying and meat/fish smoking application. The isometric view of the dual operated passive solar cooking and drying system is presented in Figure 1.

The dual operated passive solar cooking and drying system was made into trapezoidal shape which makes the back face of the cooker slightly higher than its front face thus to reduce the shading effects during sun movement and enable drains off condensation / rain showers morning dues precipitates off the glassing. The system can as well perform desalination / distillation for water purification.

For the purpose of solar drying application, two ducts ventilation openings (Air inlet and Air outlet) were provided at the opposite faces of the developed solar cooker shown in Figure 2, to enable cross ventilation when used as a dryer, air passes from the lower part and pass through to take away moisture from the drying specimen and finally moist humid air evaporates and exit at the outlet vent situated at a higher opposite level. In this way, the solar cooker will be able to carry out dual operations of drying and cooking of different household commodities with high moisture content like tomatoes, meat, fish and spices. The air inlet is made at lower position than the outlet to enable optimum utilisation of natural ventilation. These two vents must be kept closed during cooking application of the system.

The solar cooking and drying system can be constructed from varying locally available materials. The system consists of solar collector tray, glazed cover, outer casing and insulation. The system sizing was mainly based on the common available materials. For example, glass and mirror sizes of 0.6m x 0.9m are common in the rural areas. These materials are readily available at affordable cost to most families in the developing world. Insulation plays a significant role in retaining the generated thermal energy; therefore, materials with lower U-value should be used. For this work, a polythene packaging material was used because it is recyclable, non-toxic and light weight. Plywood was also used on the system outer casing. This served as part of the system insulation that retains the collected radiation. A minimum insulation of 5cm was provided for all the sides and bottom walls of the collector. Gloss paint or water resistant material was used to protect the wood against the weather.

The developed dual operated system also incorporated an 8 litres capacity thermal energy storage tank also shown in Figure 2. Both sensible and PCM latent heat storage materials could be used in storing excess heat energy for use at later time, when the sun declines.

## 3.0 SOLAR COOKING AND DRYING PERFORMANCE EVALUATIONS

### (a) Drying performances tests:

Solar drying application of the dual operated passive solar cooker was first tested without thermal storage using a simulated radiation intensity of 500W/m$^2$. The system air temperature stagnation test shown in Figure 3 indicate 23$^o$C, 24$^o$C and 80$^o$C for Ambient air ($T_a$), Air-inlet ($T_i$), and Air-outlet temperatures ($T_o$), respectively. The air inlet was almost equal to the ambient temperatures with a difference of only 1$^o$C.

When 4 litres of water ($H_2O$) was used in the storage tank, air outlet temperature drops from 80$^o$C to 72$^o$C as shown in Figure 4. The inlet and ambient temperatures remain the same as above, showing a 48$^o$C temperature difference. Also when the sensible heat storage material (water) was further increased to 8 litres of water in the storage tank, the outlet air temperature further dropped to 62$^o$C as shown in Figure 5.

The initial solar cooking performance test was conducted using a transparent plastic utensil. Parboil basmati rice and water of 0.70 kg was cooked under a simulated solar radiation intensity of 500W/m$^2$. The cooking specimen (rice) was washed and then a proportion of water was added at 1:2 ratio and then placed directly into the cooker. The rice got cooked at a temperature range from 82$^o$C to 95$^o$C in 3 hrs time with a maximum cooking pot temperature of 95$^o$C as shown in Figure 6.

Secondly a stainless steel cooking pot was used to evaluate the cooking performance of the developed solar cooker. The metallic cooking pot of 200mm diameter and 100mm height had partially transparent lid cover. This enabled physical observation of the cooking process in addition to the measuring transducers. Three different cooking pots were used to assess the cooking performance of the dual operated solar cooking and drying device. Figure 7 shows; (A) The transparent plastic pot, (B) Unpainted metallic pot and (C) Painted metallic pot.

Another cooking test was conducted with unpainted stainless cooking pot under similar condition with the transparent cooking pot as shown in Figure 8.

The system was further tested using different thermal storage materials including water, vegetable oil, waste engine oil and selected PCM materials for cooking. The results, which is shown in Table 1, shows that the system could replace most of the current conventional cooking systems in the arid and semiarid climates, and have ability to provide heat retention for up to 5 hours using 4 litres recycled vegetable and engine oils. The heat retention period could practically be further extended when PCM materials are used as a heat storage medium owing to its latent heat storage capability.

### (b) Cfd Simulation Of Solar Drying Process

The system is envisaged to be used for domestic food crops drying as well as for meat roasting and meat/fish drying applications. These involve optimization of vent positions to enable the realization of effective operating conditions within the system. In this simulation exercise, the initial air in-let vent was fixed at a position as low as possible to enable ambient air entering the drying chamber naturally. The incoming air will pass through the specimen to take up the moisture, enabling the moist air to escape at the out-let vent, which is slightly above the inlet level of the system. Fluent 6.1 is the CFD code employed to evaluate the best optimum vents positions of the dual operated passive solar drying system.

Five cases were tested by gradually changing the vertical position to 20mm above the default position. The results obtained from these five different positions are shown in Figures 9-18. The recorded temperature differences (ΔT) in all five tested CFD cases, were within the functional temperature range that could perform multiple domestic cooking and drying applications as required.

.Comparative results of all the five evaluated cases on air flow pattern of the drying system are presented in Table 2. The average temperatures inside the drying chamber of the system reduce as the duct position is due to air density variation, the air escapes from the system when the vent position is lifted up resulting in more heat loss at the air outlet duct ($T_{out\text{-}let}$) as compared to the lower duct position.

The results have shown a continuous slight temperature increase in the exit ($T_{outlet}$) of the dual operated passive system whenever the outlet vent was moved upwards. The estimated temperature difference between the inlet air and outlet air vents were 51°C (min) and 59°C (maximum) for the evaluated vent size. The recorded temperature differences were all within acceptable range for most domestic crops drying applications. The solar drying system's air flow pattern, showed the need for a drying rack, so that the drying specimens could be lifted slightly above the collector bottom. This would serve two purposes: First, it

enables more convective heat to the drying specimen to facilitate the system drying process; and secondly, it enables better ventilation inside the drying system. The temperature contours of the five CFD simulated cases, showed higher temperatures at the air outlet ducts at higher positions of the drying system. This justifies the use of drying rack placed a little higher from the base for better air circulation and to achieve drying crops items with of high moisture contents like tomatoes. The last cases, i.e. case-4 and case-5 showed better buoyancy air circulation and higher temperature distribution inside the dual operated solar cooking and drying system.

## 4.0 CONCLUSIONS

The developed dual operated passive solar cooking and drying system with phase change material (PCM) storage, if strategically supported and popularised for use in the developing world would bring a huge benefit economically, environmentally and health wise. Most Passive solar thermal energy systems are easily constructed from locally available materials having in mind the economic status of the end users. Reliance on fuel-wood and cow-dung as predominant heating and cooking energy source in the developing world is causing a serious damage to the landscape. Game reserves, thick forests including reserved shelter-belt are fast diminishing. Unsustainable energy use needs careful attention. These are currently neglected by governments and the private sector. Solar thermal energy could be a prominence sustainable means of powering water/space heating, cooking, drying, distillation and ventilation etc. If properly harnessed, especially in the developing world, solar energy would make a tremendous savings economically and environmentally due to the promising abundance and free insolation throughout the year.

Renewable energy sources such as solar energy cannot be depleted for all practical purposes. In contrast to fossil fuels, they are clean sources of energy and do not pollute the environment during process of power generation. It is clear therefore that in the not distant time, renewable energies will dominate the world's energy system, due to their inherent advantages such as mitigation of climate change, generation of employment and reduction of poverty, as well as increased security to the existing energy supplies.

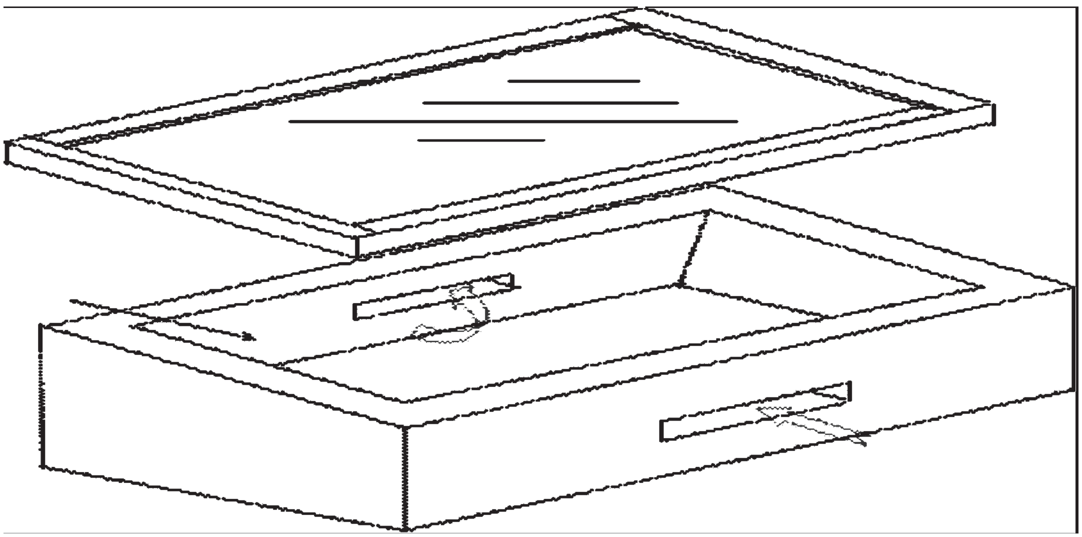


Figure 1: Isometric view of the dual operated solar cooking and drying system

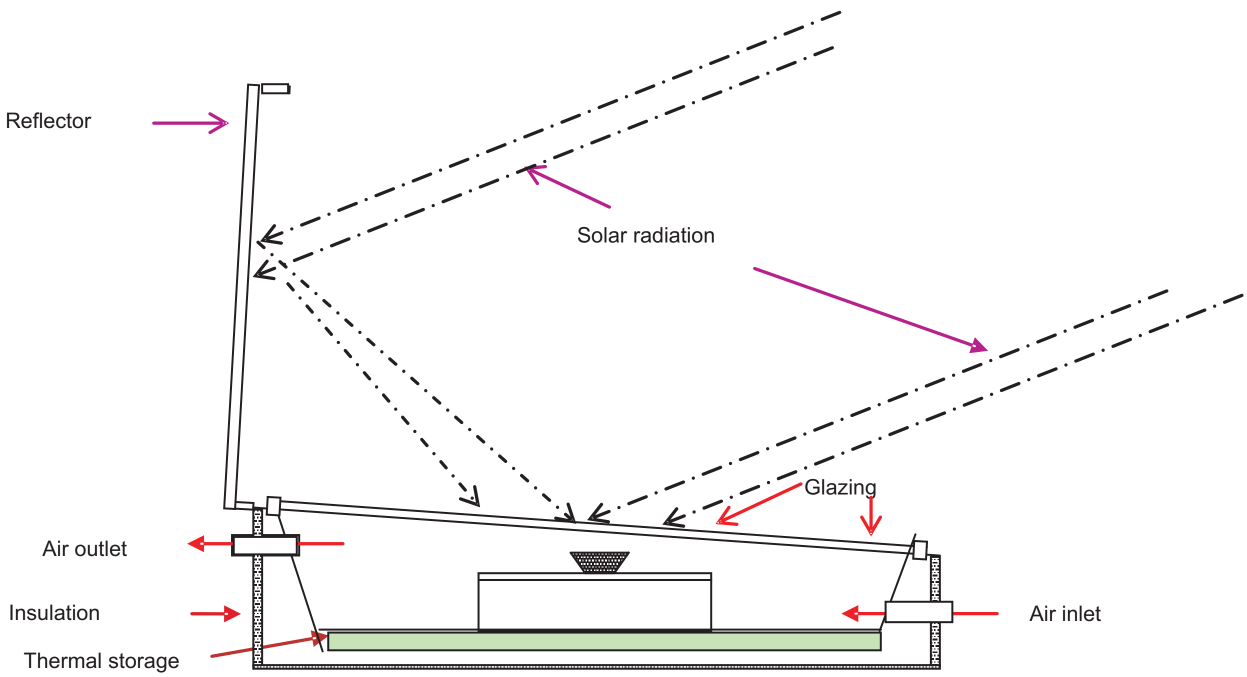



Figure 2: Dual operated (PCM) solar cooker and dryer

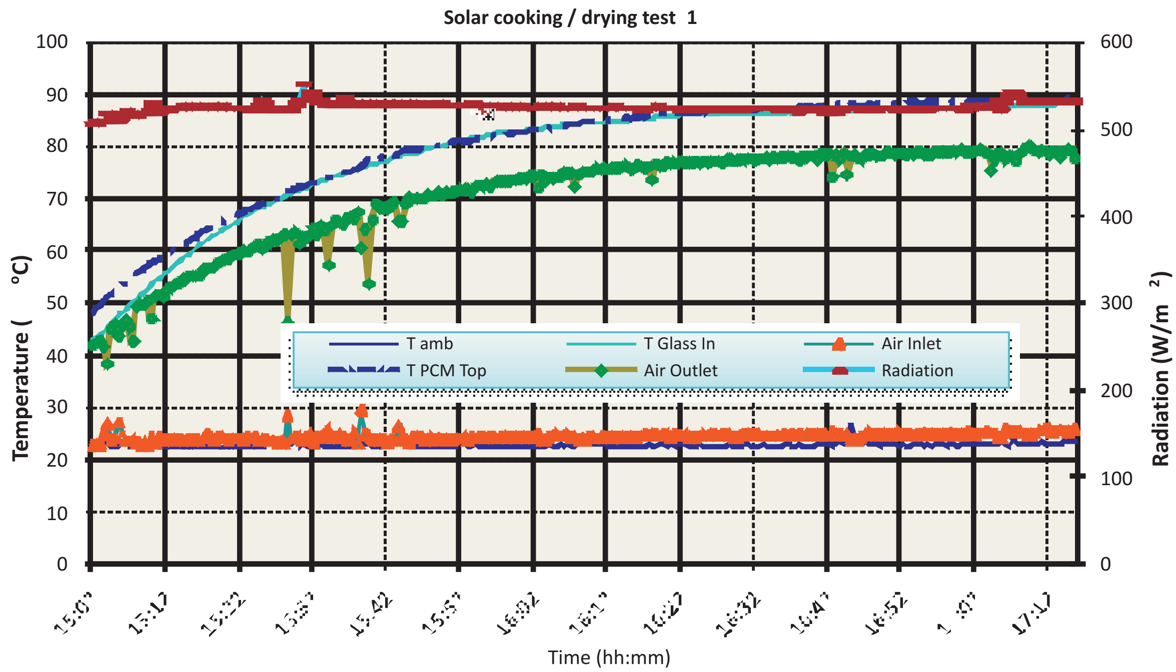



Figure 3: Solar cooking / drying stagnation test 1

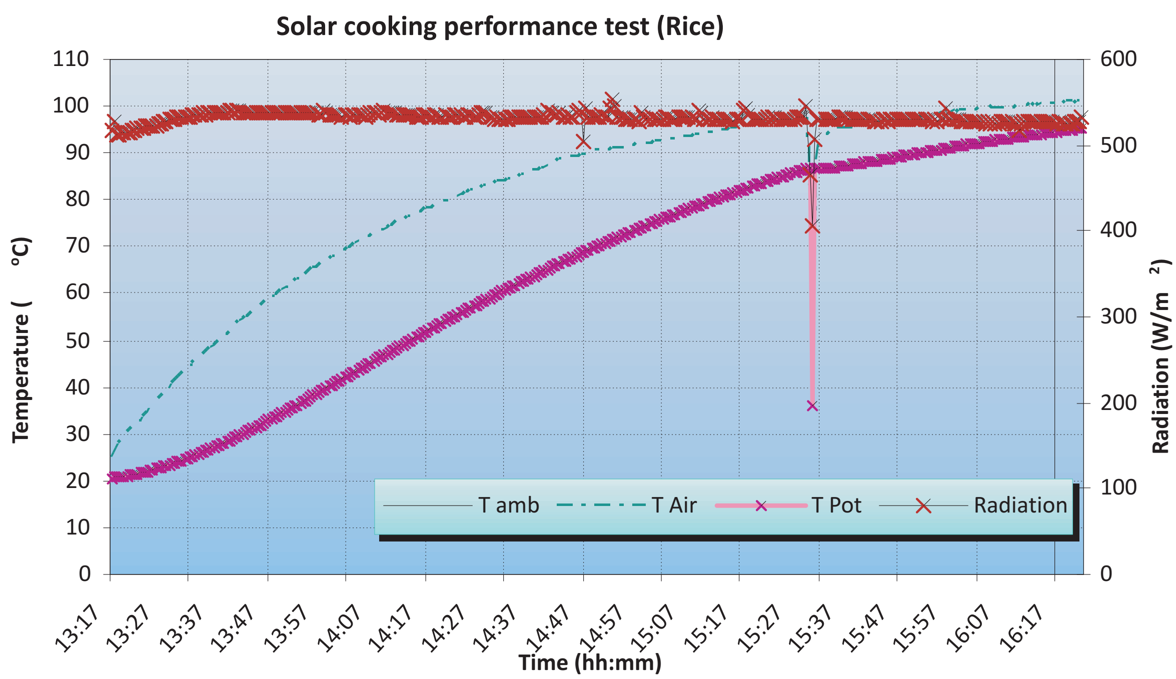



Figure 4: Solar drying stagnation test with 4 litres $H_2O$ sensible thermal heat storage

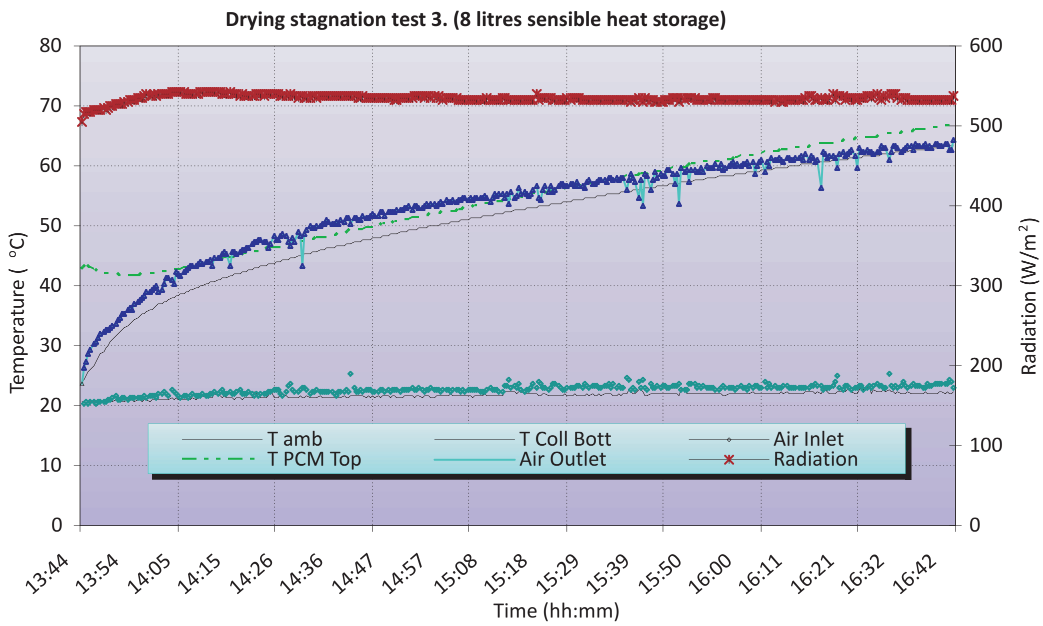



Figure 5: Drying with 8 litres of $H_2O$ sensible heat storage

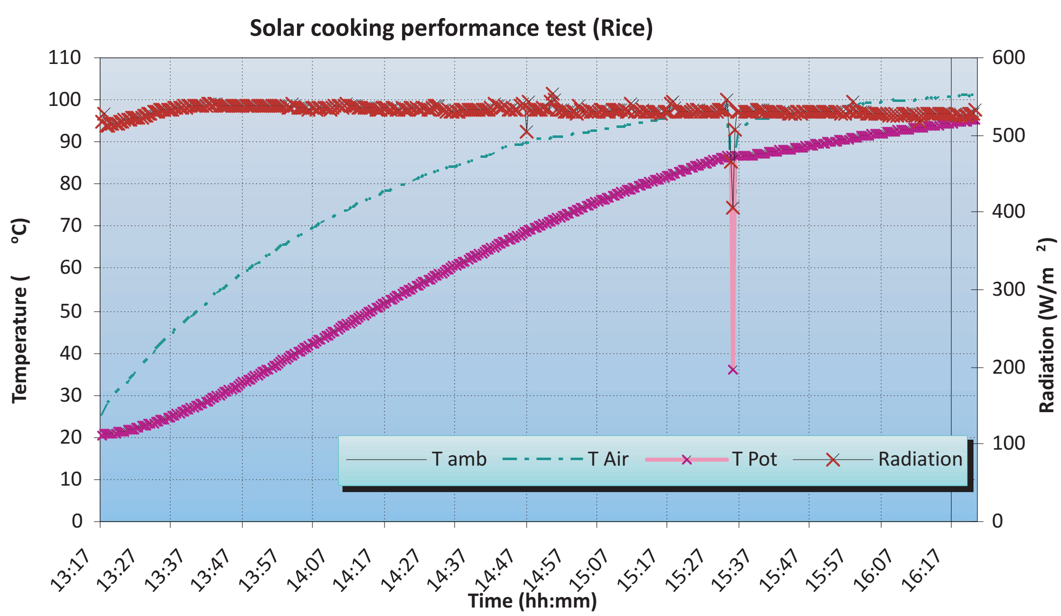



Figure 6: Rice cooking performance test 1


Figure 7: Sample cooking pots used.

Figure 8: Indoor cooking test of the dual operated solar cooking & drying system

Table 1: Cooking Performance Analysis using 4litres ofvarious storage Materials

| Material quantity | Cooking period | Cooling period | Max plate Temp. | Storage Material |
|---|---|---|---|---|
| 4 litres | 3 hr 57min | 4 hrs 40min | 72°C | Water |
| 2 litres | 2 hrs 30min | 5 hrs 25min | 82°C | Organic material. |
| 4 litres | 1 hr 30min | 6 hrs 08min | 82°C | Encapsulated material. |
| 4 litres | 1 hr 30min | 4 hrs 27min | 82°C | Veg. Oil |
| 4 litres | 1 hr 30min | 4 hrs 25min | 83°C | Engine Oil |

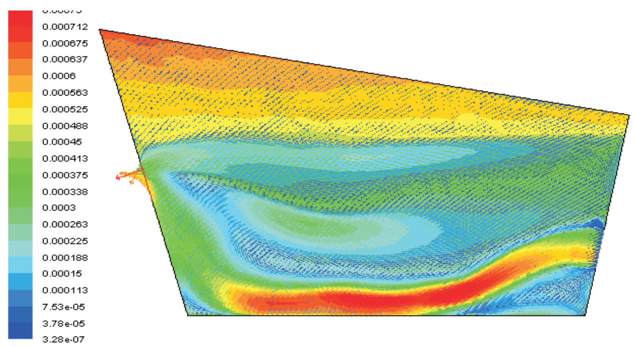


Figure 9: Case -1 Velocity vectors ($m^2$) with outlet vent duct 100 mm above the lower vent

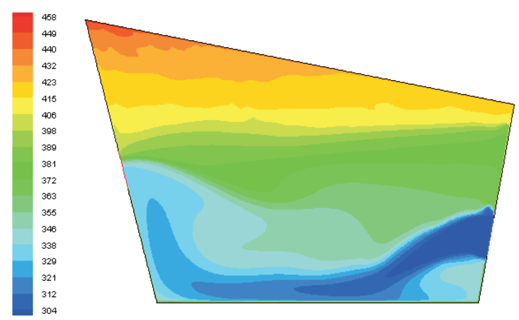


Figure 10: Case -1 Contour of the statistic temperatures (k)

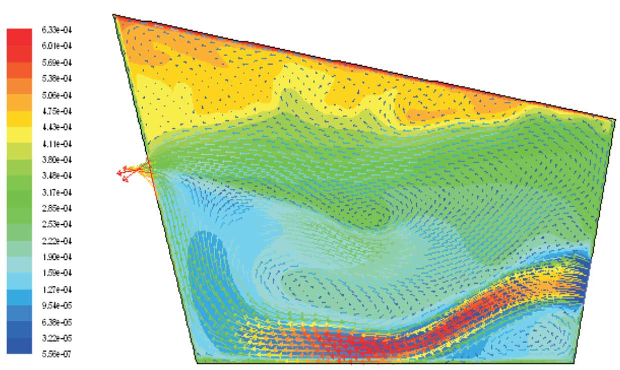


Figure 11: Case-2 Velocity vectors ($m^2$) with outlet vent duct 120 mm above the lower vent.

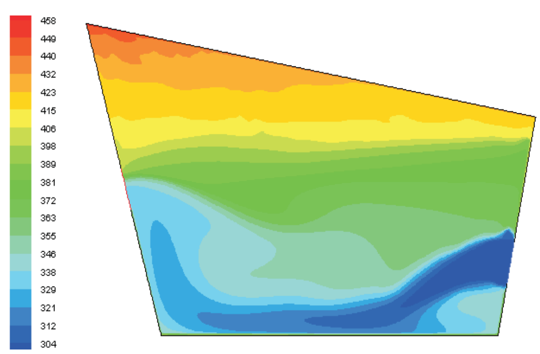
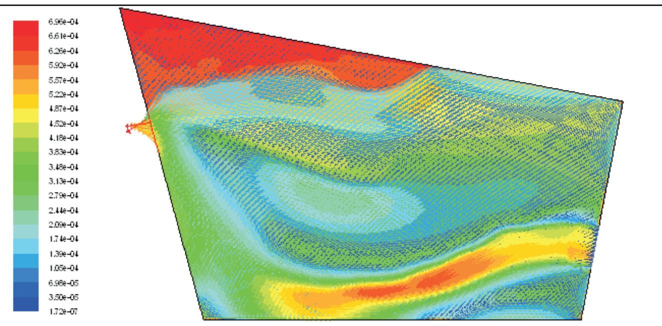


Figure 12: Case-2 Contours of the statistic temperatures (k)

Figure 11: Case-2 Velocity vectors ($m^2$) with outlet vent duct 120 mm above the lower vent.

Figure 12: Case -2 Contours of the statistic temperatures (k)



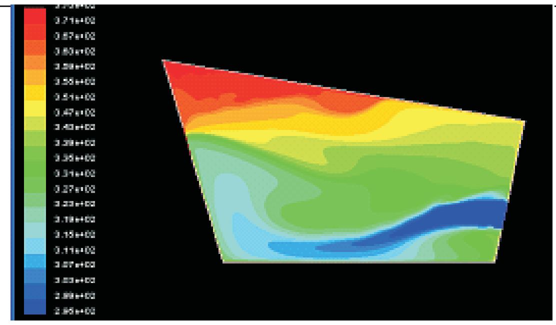
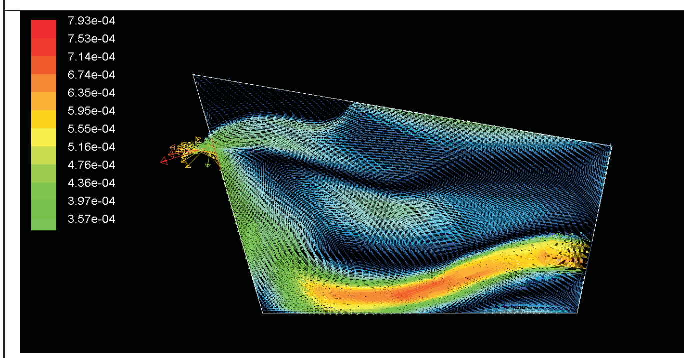


Figure 13: Case - 3 Velocity vectors ($m^2$) drying with outlet vent duct 140 mm above the lower vent

Figure 14: Case-3 Contours of the statistic temperatures (k)



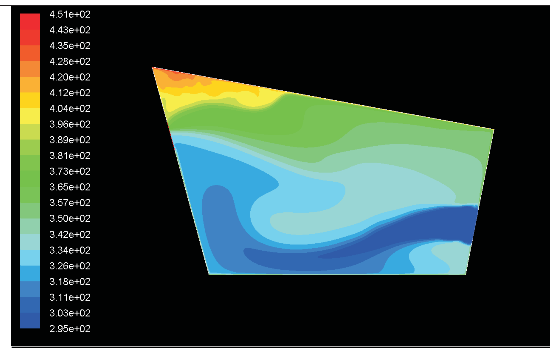
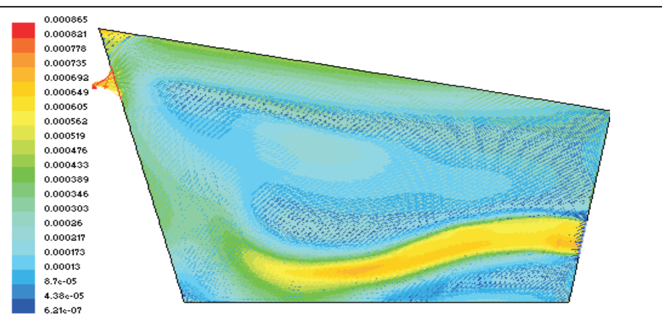




Figure 15: Case-4 Velocity vectors ($m^2$) with outlet vent duct 160 mm above the lower vent.

Figure 16: Case - 4 Contours of the statistic temperatures (k).



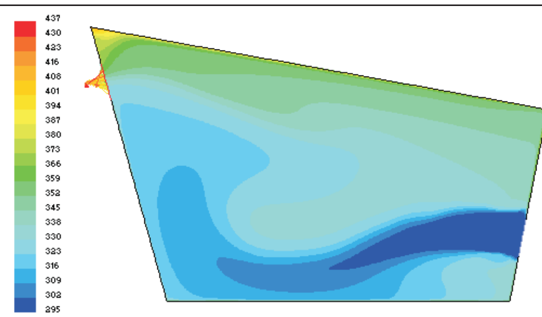


Figure 17: Case - 5 Velocity vectors (m2) application with outlet vent duct 220 mm above the lower vent.

Figure 18: Case -5 Contours of the statistic temperatures (k).

Table 2: Comparative performances of the air flow patterns of the drying systems

| *Air Outlet Duct position* (mm) | *T Inlet air* $T_{Inlet}$ (°C) | *Outlet air* $T_{Out\text{-}let}$ (°C) | *Inside average air* $T_{Inside}$ (°C) |
|---|---|---|---|
| 100 | 22 | 73 | 93 |
| 120 | 22 | 77 | 79 |
| 140 | 22 | 78 | 70 |
| 160 | 22 | 79 | 68 |
| 220 | 22 | 81 | 65 |

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# CHALLENGES AND PROSPECTS OF ENERGY EFFICIENCY AND CONSERVATION

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## ABSTRACT

A critical look into the challenges of energy efficiency and conservation in Nigeria and how these can be addressed is brought into focus in this paper. Power generation and distribution in Nigeria is still a major stumbling block to economic development, coupled with the fact that the fossil fuel sources needed for generation of power are dwindling. To address this, renewable sources need to be explored and exploited. Proper management, via energy efficiency and conservation, of these resources would help meet future demands and create a cleaner environment for all.

Energy theft, poor billing schemes, ignorance, higher cost of energy-efficient alternatives among others, are some of the impediments in putting energy efficiency and conservation into practice. The Government is, however, taking steps to overcome these challenges by creating research centers to tackle these issues. However, more still needs to be done in policy implementation to make energy efficiency and conservation a reality.

***Keywords: Efficiency; conservation; challenges;***

## 1.0 INTRODUCTION

In recent times, world debate on energy issues is predicated on the availability of sustainable and affordable energy supply. As the evidence of climate change and dwindling fossil fuel reserves become a reality, most world leaders are searching for ways to ensure that their economies are not stagnated in the face of these challenges – Nigeria is no exception.

Currently, Nigeria is a net exporter of energy (mostly in the form of crude oil) from which it earns the largest percentage (about 91%) of its foreign exchange. The fact that energy demand is expected to increase has raised questions concerning the net availability of this form of energy in the future. For instance, Nigeria's energy demand increased from $4.2 \times 1.0^{14}$ BTU in 1980 to$1.13 \times 10^{15}$ BTU in 2004. This increase in demand is expected to continue as the country becomes more industrialised, and as the standard of living and population increases. It is also important to note that to meet the current and future demand in a sustainable manner, other primary energy sources will have to be explored and exploited.

Exploiting renewable energy sources like wind, solar and thermal, is one way of meeting energy demands in a sustainable manner. However, there exists another 'energy resource' which is clean, not intermittent and does not compete with food crops. This 'energy resource' is referred to as Energy Efficiency. This term is associated with using less energy to achieve the same amount of work. Given that 'money saved is money earned', it is considered as an energy resource because energy saved can be available for other productive uses. Though currently not very popular in this part of the world, it is believed that energy saved through efficiency will help meet future demands, reduce the need for more power plants and reduce pollution generally. This would encourage stakeholders to invest more in research of energy efficient materials among other things. Nigeria must systematically align itself to this recent trend and must be able to adopt these technologies that ensure energy efficiency, as they become available.

In what follows, the challenges faced by Nigeria in achieving energy efficiency and conservation are discussed in detail.

## 2.0 CHALLENGES AND PROSPECTS

The challenge facing energy efficiency and conservation encompasses the use of energy inefficient products, behavioural problems and dependence on energy sources whose exploitation are harmful and leads to environmental degradation.
Electrical energy, being the most widely available generic form in which energy is utilized, is the focus of this paper. Therefore the challenges and prospect for energy efficiency is discussed below in terms of electrical energy.

## 2.1 BEHAVIOURAL PROBLEMS

The behaviour of individuals with respect to energy consumption presents a major problem to the implementation of energy efficiency in Nigeria. These problems include energy theft, poor billing and ignorance.

### 2.1.1 Energy Theft

Electricity supply in Nigeria is currently not adequate for the citizens' needs. This limited supply has the attendant effect of people struggling to get electrical power by all means necessary. Some individuals resort to making illegal connections to power lines (commonly known as tapping) or bribing power authority officials to give lower bills than what they actually consumed or to supply power to them instead of others in cases of load shedding. Dangers associated with energy theft include fires, electrocution, death, etc to the perpetrator and also to innocent people.

A way of curbing this theft is via the use of electronic card meter systems, in place of the older electromechanical ones. In advanced countries, the use of smart metering systems helps reduce electrical load, and also monitor deviations from expected usage, or any other anomaly. Since these meters can be accessed remotely, any anomaly or tampering that is detected would trigger alarms at the supplier's end. Energy theft makes energy efficiency and conservation practices difficult as there are no proper records of energy usage and those who consume energy efficiently cannot be acknowledged. Also, it makes network planning and optimisation difficult.

### 2.1.2 Poor Billing Scheme

Some consumers of electricity in the country are given estimated bills. In other words, the amount of money they pay for electrical energy is not commensurate with the amount of energy they consume. For instance, whether a consumer uses 500kWh or 10,000kWh of energy for a particular period of time, he would be billed the same amount of energy. Therefore, such consumers would see no need to implement conservation techniques. The most effective way of encouraging the practice of conservation techniques is to show consumers the gains they can reap, and estimated billing system would stand as an obstacle to this. To solve the problem associated with poor billing, more efforts should be put into the implementation of the pre-paid system of billing. This would ensure that consumers see the effect of conservation measures they observe, such as switching off appliances or buying energy efficient appliances and would act as a stimulant for the propagation of energy efficient and conservation habits.

### 2.1.3 Ignorance

There is generally a low level of awareness on ways of conserving energy. Several people that the NCEEC interacted with while creating awareness on the need for energy efficiency and conservation consider it to be a new idea and confessed to the fact that they leave appliances and lights on without thinking of the consequences. Below is a summary of comments at an awareness session NCEEC undertook recently.

From fig 1, it can be seen that a large percentage of respondents encouraged energy efficiency and conservation programmes. Thus, mass enlightenment campaigns via fliers, radio jingles, stickers, posters, etc, should be carried out to educate the people. Stickers and posters bearing information or tips on how people can conserve energy at home, offices and industries are presently being distributed; however, a lot still remains to be done to increase the awareness level.

## 2.2 USE OF ENERGY INEFFICIENT APPLIANCES

There are several electrical appliances common to the industrial, commercial and domestic sector of any society. These include lighting systems and HVAC (heating, ventilation and air-conditioning) systems. Other electrical devices are industrial components like electric motors, boilers, compressors, etc.

### 2.2.1 Lighting Systems

Most homes and industries in the country still use incandescent and halogen lamps which generate light and heat are consequently inefficient. However, there are energy-saving lamps such as compact fluorescent lamps (CFLs) and light emitting diode (LED) lamps that consume less energy and provide better illumination. For example, a 14 watt CFL is as bright as a 75 watt incandescent lamp. Consequently, the energy wasted in industrial, commercial and domestic lighting would be greatly reduced. To further illustrate this point, NCEEC replaced a total of 442 incandescent bulbs with CFLs of appropriate luminance at the University of Lagos Guest House (see Tables 1 and 2 below). This exercise resulted in the reduction of lighting loads from 25.92KW to 4.29KW. This represents approximately 83% reduction in lighting energy bill.

HVAC systems are among the highest energy consumers in both the domestic and industrial sectors and thus present great opportunity for savings. The challenge posed by HVAC systems is basically due to the energy needed to operate electric motors or compressors powering its centrifugal pumps and fans. To address this problem, it should be noted that for HVAC systems to operate efficiently, it must meet optimum heating and cooling needs which vary according to the time of the day and the season. In this case, variable air volume systems with variable speed drives would play a major role. These regulate the power used by the electric motors or compressors and consequently the speed of centrifugal pumps and fans, ensuring that the HVAC systems do not run on full power all the time but use only the power needed at a particular time. This would reduce the energy used by HVAC systems significantly. Besides this reduction in energy, comfort level of a building would be increased significantly since it would neither be overheated nor overcooled.

### 2.2.3 Other Electrical Appliances

The use of other electrical devices poses a problem to energy efficiency and conservation in Nigeria. For example, some consumers still use the Cathode Ray Tube (CRT) television sets and computer monitors. These CRT television and monitors consume an enormous amount of energy compared to their Liquid Crystal Display (LCD) counterparts. Also, older fridges and freezers, use more energy than newer models. Switching off appliances and unplugging completely rather than putting them on standby, replacing worn out fridge and freezer seals, and regular cleaning and maintenance of these appliances are some ways of conserving energy.

## 2.3 ELECTRIC MOTORS, COMPRESSORS AND BOILERS IN INDUSTRIES

Most industries in Nigeria make use of electric motors, compressors and boilers which are enormous energy consumers and constitute a great percentage of energy consumed by the industries. Consequently, there is great potential for savings in industries given the efficient use of these electrical devices.

### 2.3.1 Electric Motors

Electric motors are prime movers in the manufacturing industries. They consume the highest amount of energy compared with other industrial energy consuming devices. Certain components of motors degrade with time and operating stress and contact between moving surfaces causes wear. Wearing of motor parts is exacerbated by dirt, moisture, and corrosive fumes, and when lubricants are misapplied these parts become overheated. Electrical insulation also weakens over time with exposure to voltage unbalance and temperature. Measures of reducing the power consumed by these motors include some of the methods discussed below.

#### *2.3.1.1 Power factor correction*

A large percentage of the electric motors used in the industry are of the 3-phase induction motor type. They are very rugged, simple by design and operation and run at a fixed speed. In operation they draw real and reactive powers, the latter contributing to the increase in energy consumption. The electricity service provider (PHCN) bills the company higher for drawing reactive power at a lower power factor. This has continued to pose a challenge to the energy demand and stability.

Installation of capacitor-banks in parallel with the load to reduce reactive power consumption will lower the energy drawn by these motors[1]. From a recent industrial visit to a five-star hotel in Lagos, it was found that the installation of three (3) 125KVAr banks of capacitors increased the average power factor of the electric motor systems from 0.80 to 0.99. This translates to roughly 25% reduction in the cost of electrical energy.

The same consideration applies to the wide spread use of CFL which is being vigorously advocated. This will increase the demand for reactive power that is bound to affect the ability of the power provider to deliver power. The implication is that power delivery will either be more expensive or the consumer will have to pay more for a CFL that has integrated PFC.

#### *2.3.1.2 Heating of motors*

It is known that a higher operating temperature shortens motor life. According to the U.S Department of Energy, for every 10°C rise in operating temperature, the electrical insulator life is cut in half. This reduction in insulation would lead to losses in form of heat which is power wastage. Eventually the insulation breaks down and the electrical windings burn up and the motor is destroyed. To reduce these loses regular maintenance of the cooling fans of electric motors should be carried out and the ambient operating conditions be, as much as possible, as specified by the manufacturer.

### 2.3.2 Boilers

Regular boiler inspection is important for their optimal function, life span and energy efficiency. As boilers are high energy users, inefficient operation means wasted energy and increased costs. Performance monitoring of boilers is imperative in process industries as the major portion of the operating cost is determined by the fuel consumed in the boilers due to the deposit soot or scales they produce [2]. There is a loss in evaporation capacity due to the accumulation of these soot/scales and is given by

$$\frac{1}{U} = A + B \times t$$

Where: $U$ is the heat transfer coefficient in kcal/hr/m$^2$/$^o$C

$t$ is the time lapsed since last cleaning.

A ≥ Normal efficiency at full load
B ≥ Efficiency after time t

Maintenance activities should be carried out regularly in order to prevent degradation of equipment and minimize losses.

### 2.3.3 Compressors

For compressors to be more energy efficient, weekly or monthly maintenance should be carried out with a view to reducing compressed air leakages and maintaining an optimal air storage strategy to help balance supply with demand. These will improve and enhance the efficiency of the compressor and reduce its work load.

Also as motors generate a lot of heat, fans are pre-installed to reduce the temperature. These fans, with time, tend to use more energy to provide the same level of cooling. Regular maintenance of operational fans and repair of broken-down ones would reduce the energy consumption of the motors and improve motor reliability. They should also be located in wellshaded and ventilated areas.

#### 2.3.4 Transmission Efficiency

Transmission equipment including shafts, belts, chains, and gears should be properly installed and maintained. When possible, synchronous belts or chains should be used in place of V-belts. Helical gears which are more efficient than worm gears should be used with motors under 10 hp.

### 2.4 POLICIES AND REGULATION

#### 2.4.1. Importation of Incandescent Bulbs and Inefficient appliances

Allowing importation and manufacture of incandescent bulbs and inefficient appliances will continue to increase the energy consumption in the country. Government should as a matter of urgency encourage the importers to bring in energy-efficient appliances and lamps into the country. This can be achieved by granting duty-free imports or tax rebates to these importers so as to discourage the importation of the inefficient appliances. As an example, some countries have come up with policies to promote the use of energy saving lights, via subsidies on energy-efficient lights and appliances and a clamp on production and importation of inefficient appliances.

#### 2.4.2 Absence of tax rebate and subsidy on renewable energy systems

The cost of procuring renewable energy systems is relatively expensive. To reduce the cost of renewable energy systems, government should give tax rebates to manufacturers and marketers of these systems. Also, government subsidies would encourage the purchase and use of renewable energy technology. It is therefore imperative for the government to incentivise the adoption of renewable energy alternatives.

#### 2.4.3 Monopoly

The challenge of having an establishment without competitors in its line of business, as it has been found from the Nigerian experience, is that monopolies encourage bureaucratic corruption, nepotism, bureaucratic bottle-necks, buck passing and poor service delivery. An example can be found in the Telecommunications sector where competitors within and outside Nigeria where granted operational licenses. The success story of the telecommunications sector in Nigeria shows that if government creates an enabling environment for private sector participation it would yield tremendous benefits. Else, expected investors in the industry would not be forthcoming and the benefits of privatization would not be realised in the near future[3].

Therefore, the onus is on government to break the monopoly of the electrical sector and create an enabling environment were venture capitalists can explore the associated risks and return on investments on electrical generation, distribution and service delivery.

## 3.0 CONCLUSION

Energy theft in the power sector, poor billing issues and ignorance are some of the challenges being faced in implementing energy efficiency and conservation and harnessing its benefits. The intervention of the government and active participation of the general public are crucial factors in overcoming these challenges.

Lighting systems, HVAC systems and electrical appliances are common areas that present great opportunities for energy savings in Nigeria's industrial, commercial and domestic sectors. Reasonable savings can be achieved with the use of CFLs in lighting, variable frequency drives in HVAC systems, implementation of power factor correction in motors, and regular maintenance of equipment. The Nigerian Government has taken important steps towards establishment of research centers to help formation of energy efficiency and conservation policies. However, policy implementation is the key to realizing the set objectives and Government should continue to strengthen these institutions.

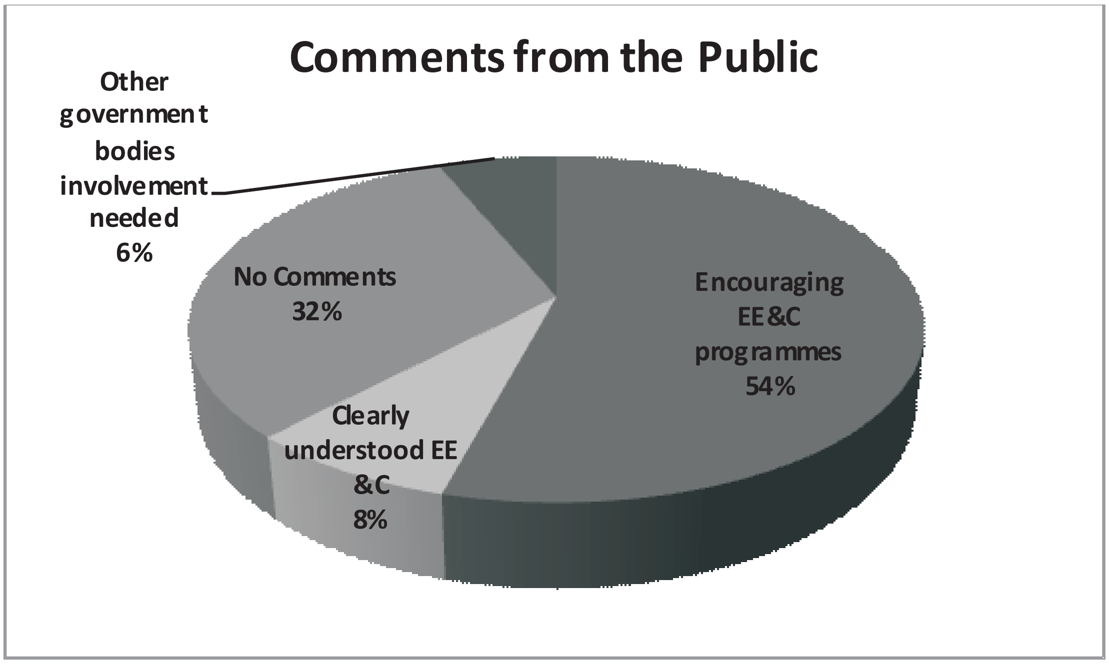


Fig 1: Comments from 240 members of the public

Table 1: Shows the total number of incandescent lamps at different locations

| NO | LOCATION | QUANTITY | WATTAGE | TOTAL POWER |
|---|---|---|---|---|
| 1 | Corridor | 84 | 60 | 5040 |
| 2 | Staircase | 30 | 60 | 1800 |
| 3 | Restaurant | 44 | 60 | 2640 |
| 4 | Conference Halls | 24 | 60 | 1440 |
| 5 | Rooms and Toilets | 260 | 60 | 15000 |
| | TOTAL | 442 | | **25,920** |

Table 2: Showing the total number of Compact Fluorescent lamps replacing incandescent lamps at different locations

| NO | LOCATION | QUANTITY | WATTAGE | TOTAL |
|---|---|---|---|---|
| 1 | Corridors | 84 | 18 | 1512 |
| 2 | Staircase | 30 | 14 | 420 |
| 3 | Restaurant | 44 | 14 | 616 |
| 4 | Conference Halls | 24 | 11 | 264 |
| 5 | Rooms | 200 | 5 | 1000 |
| 6 | Toilets | 60 | 8 | 480 |
| | TOTAL | 442 | | **4,292** |

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# Optimization of Biodiesel Production: Transesterification of Edible and Non-Edible Vegetable Oils

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## ABSTRACT

In this study, both edible (palm oil) and non-edible oils (Jathropha and Neem oil) were used to optimize the biodiesel production process variables like catalyst concentration, amount of alcohol required for reaction, reaction time and reaction temperature. Biodiesel production from different edible and non-edible vegetable oils was compared in order to optimize the biodiesel production process. A two-step and single-step transesteri? cation process was used to produce biodiesel from high free fatty acid (FFA) non-edible oils and edible vegetable oils, respectively. This process gives yields of about 90–92% for J. curcas, 82–84% for neem, and 90–95% for palm oil using potassium hydroxide (KOH) as a catalyst.

***Keywords:*** *Biodiesel, Transesterification, Optimization, Jatropha, Neem, Groundnut oil.*

## 1.0 INTRODUCTION

The increased use of diesel fuel resulted in depletion of its fossil reserves. This triggers for many initiatives to search for alternate fuel, which can supplement or replace such fossil fuel. In recent years, research has been directed to explore plant-based fuels and plant oils and fats as fuels have bright future (Martini and Shell, 1998). The most common that is being developed and used at present is biodiesel, which is fatty acid methyl esters of seed oils and fats and have already been found suitable for use as fuel in diesel engine. Presently the world's energy needs are met through non-renewable resources such as petrochemicals, natural gas and coal. Since the demand and cost of petroleum based fuel is growing rapidly, and if the present pattern of consumption continues, these resources will be depleted in few years. Hence, efforts are being made to explore for alternative source of energy. An alternative fuel must be technically feasible, economically competitive, environmentally acceptable and readily available (Srivastara and Prasad, 2000) Biodiesel is found to be environmentally safe, non-toxic and biodegradable (Harrington, 1986).

The raw materials being exploited commercially by the developed countries constitute the edible fatty oils derived from rapeseed, soya bean, palm, sun? ower, coconut, linseed, etc. (Korbitz, 1999). Use of such edible oil to produce biodiesel in Nigeria is not feasible in view of a big gap in demand and supply of such oils in the country. Increased pressure to augment production of edible oil has also put limitation on the use of these oils for production of biodiesel. Under such conditions, those crops that produce non-edible oil in appreciable quantities can be grown in large scale in non-cropped marginal lands and wastelands only considered for biodiesel production (Mohibbe and Waris, 2005).

Fatty acid methyl esters derived from renewable sources such as vegetable oils has gained importance as an alternative fuel for diesel engines. The edible oils such as soyabean oil in USA, rapeseed oil in Europe and palm oil in countries with tropical climate such as Malaysia are being used for the production of biodiesel to fuel their compression ignition engines (Knothe, 2002). In Nigerian context, the use of edible oils for engine fuel is not feasible; however, there are several non-edible oilseed species such as Jatropha (*Jatropha curcas*) and Neem (*Azadirachta indica*), which could be utilized as a source for production of oil.

Extensive work has been done on the transesteri? cation of non-edible and edible vegetable oils; however, no signi? cant work has been done on the optimization of Jathropha curcas, neem and bleached palm oil. An optimization study on biodiesel production for the edible (bleached palm) and non-edible (Jathropha curcas and neem) vegetable oils were done in detail with one-step alkali transesteri?cation process and two-step acid esteri?cation process, respectively with fuel property analysis of these oils.

## 2.0 MATERIALS AND METHODS

Edible (Bleached palm oil) and non-edible (Jatropha and neem oil) oils were used in this experiment. These oils were extracted at NARICT, Zaria processing plant. All the oils were ?rst ?ltered using muslin cloth mainly to remove the dirt and other inert materials from the oil and then placed in a ?ask. A round bottom ?ask was used as laboratory scale reactor for the experimental studies in this work, and a hot plate with magnetic stirrer arrangement was used for heating the mixture in the ?ask. For both edible and non-edible oils, the mixture was stirred at the same speed of 450 rpm for all test runs.

Under agitation, the raw oil was heated up to nearer to the boiling point to remove the water contaminant present in the oil. After that oil is allowed to cool down under room temperature, and the treated oil alone was taken for biodiesel production purpose. Again, under agitation, the above treated oil was heated up to a desired temperature on a hot plate. A ?xed amount of freshly prepared sodium hydroxide–methanol solution was added into the oils, taking this moment as the starting time of the reaction. When the reaction reached the preset reaction time, heating and stirring were stopped. The products of reaction were allowed to settle. During settling two distinct liquid phases were formed: crude ester phase at the top and glycerol phase at the bottom. The crude ester phase separated from the bottom glycerol phase was then washed by cold water several times until the washed water became clear. The excess methanol and water in ester phase were then removed by heating > $100^0$C.

After that, weight of the ester was taken for product yield calculation. The reaction was investigated step by step. The optimal value of each parameter involved in the process was determined while the rest of the parameters were kept constant. After each optimal value was attained, this value was adopted for the optimization of the next parameter. The parameters such as alcohol to oil molar ratio, catalyst amount, reaction temperature, and reaction time were analyzed.

### (a) Two-step esterification procedure for non-edible oils

In acid esterification, oil was poured into the flask and heated to about $55^0$C. Then 20%(v/w) of methanol was added and stirred at low stirring speed for 30 min. followed by 0.5% (v/v) of sulfuric acid. The reaction mixture was then poured into a separation funnel to remove excess alcohol, sulfuric acid and impurities. The treated oil having acid value less than < 1. 0.25 mg KOH/g was used for the alkali transesterification reaction. It has been reported that transesterification would not occur if FFA content in the oil was above 2% (Canakci and VanGerpen, 1992). The J. curcas oil has an initial acid value of 8mg KOH/g and neem oil has an acid value of 12 mg KOH/g. The experimental set-up for alkali catalyzed transesterification was the same as that was used for of acid catalyzed pretreatment. 1% of KOH was dissolved in 20 %( w/w) of methanol and half of that was poured into the flask containing an unheated mixture from acid esterification step and stirred for 10 min. After 10 min, the mixture was heated and stirred continuously to about $60^0$C, and then the remaining methoxide was added to it. The reaction was continued for next 1 hr.

### (b) One-step alkali transesterification procedure for edible oils

In alkali transesterification, treated oil from pretreatment procedure was allowed to cool at normal temperature. Meanwhile, 1 % of KOH was dissolved in 20% (w/w) methanol and half of it was poured into the unheated oil and stirred for 10 min. The mixture was heated to temperature of $55^0$C in the flask. Then added remaining mixture of methanol and catalyst to it and reaction was continued for 1h at 450rpm. After the alkali transesterification reaction was completed in edible and non-edible oils, the reactant mixture was allowed to be separated into two layers. The bottom layer having a brownish red color and containing the impurities and crude glycerol was drawn off. The esters along with the catalyst remained in the upper layer were then separated from the reactant mixtures. The transesterified product (biodiesel) after separation was first distilled to remove the unreacted methanol and then washed 2–3 times with hot water to remove the dissolved glycerol in the biodiesel phase.

**(c) Effect of catalyst concentration.**

The effect of sodium hydroxide concentration on the transesterification of the edible and non-edible oils was investigated with its concentration varying from 0.25 to 1.25 wt. % (based on the weight of raw oil). The operation conditions during the whole reaction process were fixed at the optimal level: reaction temperature of 55°C reaction time of 90 min. and 180 and 210 ml of methanol for edible and non-edible oils, respectively.

**(d) Effect of reaction time**

The reaction time of the transesterification reaction conducted at 55°C was optimized with the highest achievable mixing degree, an excess amount of alcohol (220 ml per liter of oil) and optimal sodium hydroxide concentration of 1.25 wt. % for all the oils. The transesterification time vary from 25 to 105min.

**(e) Effects of methanol amount.**

The effect of methanol amount on yield of the transesterification experiments was conducted with different ratio of methanol to oil in the range of 3:1 to 15:1. The optimized catalyst concentration time as obtained in the above sections were adopted.

***(f) Effect of reaction temperature.***

To study the effect of reaction temperature on methyl esters' formation, the transesterification reaction was carried out under the optimal conditions obtained in the previous sections. The experiments were conducted at temperature ranging from 20 to 80°C interval.

## 3.0 RESULTS AND DISCUSSION

Experimental results showed changes in ester yield content with varied catalyst concentration. As the sodium hydroxide concentration increased the conversion of triglyceride as well as the ester content also increased. Insufficient amount of sodium hydroxide resulted in incomplete conversion of triglycerides into the esters as indicated from its lower ester content. The ester content reached an optimal value when the sodium hydroxide concentration reached 1wt. % and further increase in catalyst concentration in all the cases, ester production amount decreased as shown in Fig. 1. Large amount of soap was observed in excess amount of sodium hydroxide added experiments. This is because addition of excess alkaline catalyst caused more triglycerides' participation in the saponification reaction with sodium hydroxide, resulting in the production of more amount of soap and reduction of the ester yield.

The changes in product composition with reaction time during the transesterification of the oils and the distribution of various components in the reaction system can be clearly seen. When the reaction time reached 65 min., no triglyceride was left in the product mixture, indicating complete conversion. In this experiment, glycerol started to separate within 25 min. The ester content increased with reaction time 25 min onwards and reached a maximum at a reaction time of 65 min. at 55°C, and then decrease with increasing further the reaction time (Fig. 2). The results indicated that an extension of the reaction time from 65 to 105 min. had no significant effect on the conversion of triglycerides but leads to a reduction in the product yield. This is because longer reaction enhanced the hydrolysis of esters (reverse reaction of transesterification), resulted in loss of esters as well as causing more fatty acids to form soap.

Experimental results showed that the transesterification reaction could proceed within the temperature range studied but the reaction time to complete the reaction varied significantly with reaction temperature as shown in fig. 3. It can be seen that a high product yield could be achieved at 65°C. With the temperature increase above 65°C, the product yield started to decrease. The reaction for this is that higher temperature accelerates the side saponification reaction of triglycerides.

Maximum ester content was obtained at a methanol amount of 6:1 for edible oil and 9:1 for non-edible oils. With further increase in the methanol to oil amount above 9:1, a very little effect on the biodiesel yield was observed (Fig. 4). Moreover, it was observed that for high alcohol amount added the set up required longer time for the subsequent separation stage since separation of the ester layer from the water layer becomes more difficult with the addition of a large amount of methanol. This is due to the fact that methanol, with one polar hydroxyl group, can work as an emulsifier that enhances emulsion. Therefore, increasing the alcohol amount to oil is another important parameter affecting the biodiesel yield and biodiesel purity, apart from catalyst concentration and reaction time. This result is in line with the report of many investigations based on neat vegetable oils (Meher etal, 2006; Senthil et al, 2003; Encinar et al, 2002). However, the non-edible like *Jatropha* and *neem* require 9:1 ratio of methanol to KOH to give maximum ester yield, possibly due to higher viscosity of non-edible oil than edible oils. In this case more amount of methanol is required to increase the solubility of the oil in the methanol. This leads to maximize the ester yield at high methanol concentration level. However, when compared to edible oil ester content yield was minimal in non-edible oil but glycerol yield was found to be more in non-edible oil when compared to edible oil.

## 4.0 CONCLUSION

The study on the biodiesel production process optimization of edible and non-edible oils showed that the quantity of catalyst, amount of methanol, reaction temperature and reaction time are the main factors affecting the production of methyl esters. From the results the following were drawn:

- Addition of excess catalyst causes more triglycerides' participation in the saponi? cation reaction leading to a marked reduction in the ester yield.
- Biodiesel production process is incomplete when the methanol amount is less than the optimal value. Operating beyond the optimal value, the ester yield would not be increased but will result in additional cost for methanol recovery.
- Higher reaction temperature decreases the viscosities of the oils and resulted in increased rate of transesteri? cation and shortening of the reaction time. When the temperature increases beyond the optimum level it induces a negative impact on the ester yield due to acceleration of the saponi? cation of triglycerides.
- Suf? cient reaction time should be allowed to ensure complete conversion of triglycerides into esters. However, excess reaction time did not promote the conversion but favors the reverse reaction of transesteri? cation which resulted in a reduction in the ester yield.

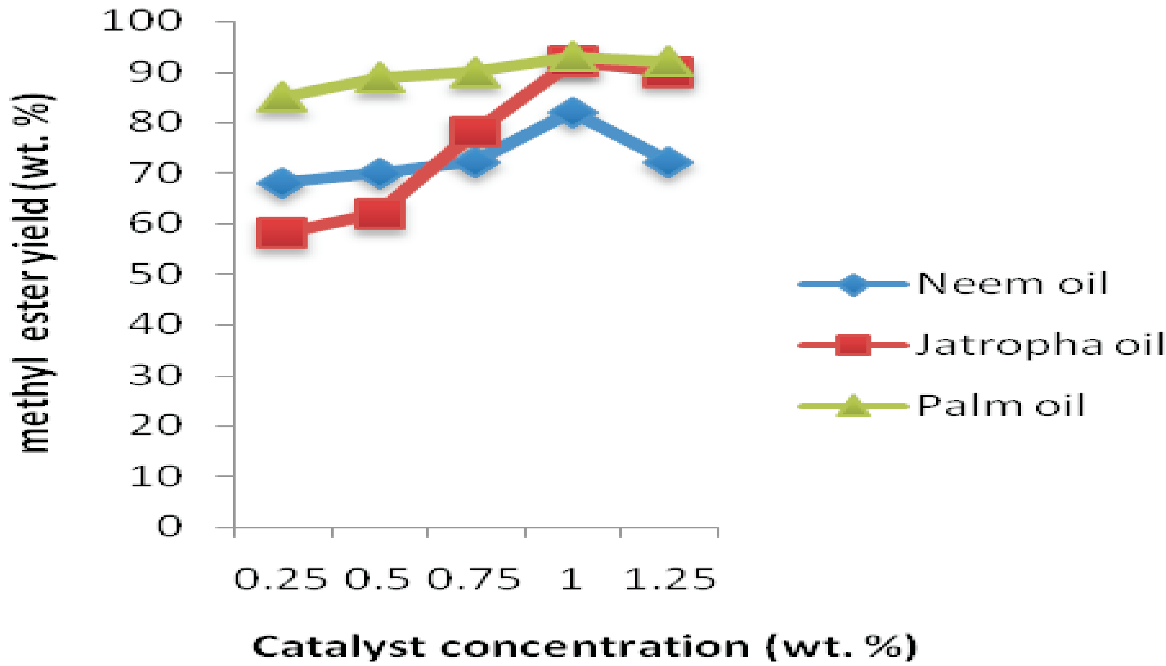


**Fig. 1 Effect of catalyst concentration on methyl esters' yield**

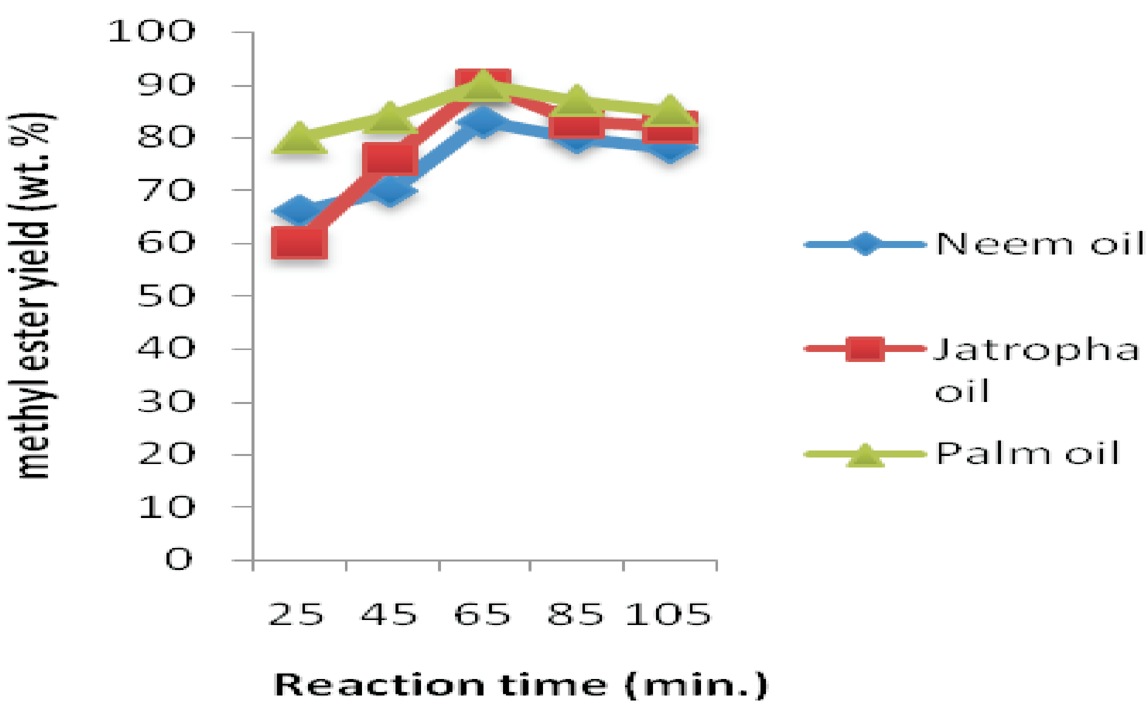


**Fig. 2 Effect of reaction time on methyl esters' yield**

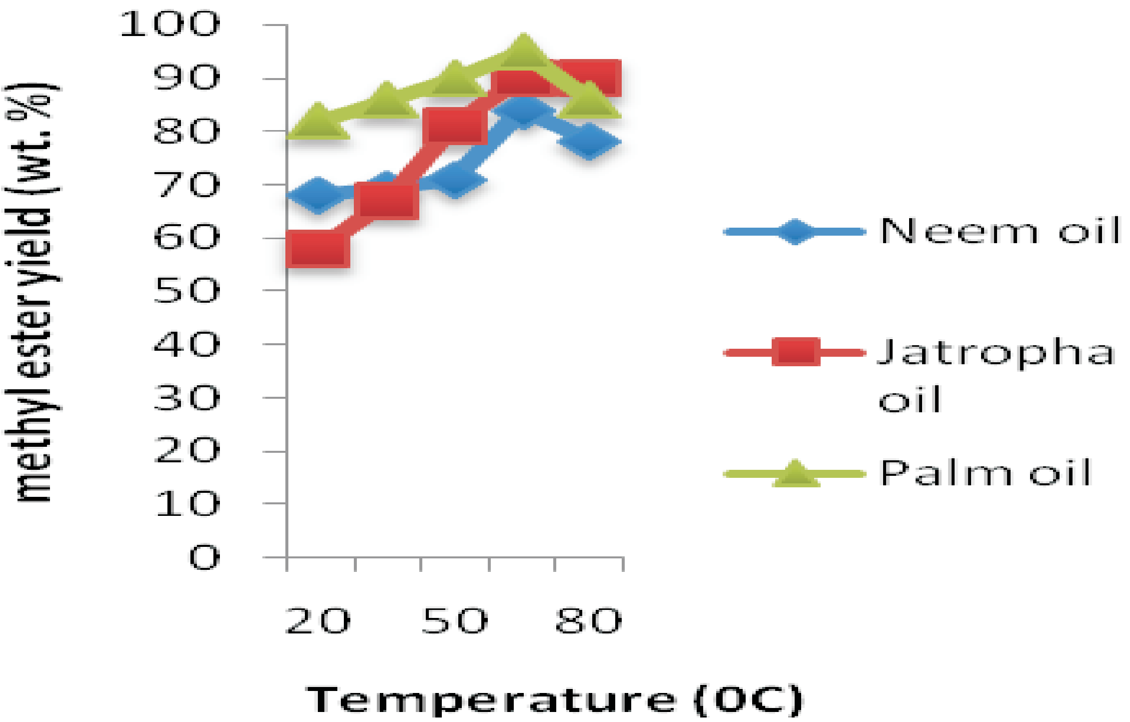


**Fig. 3 Effect of temperature on methyl esters' yield**

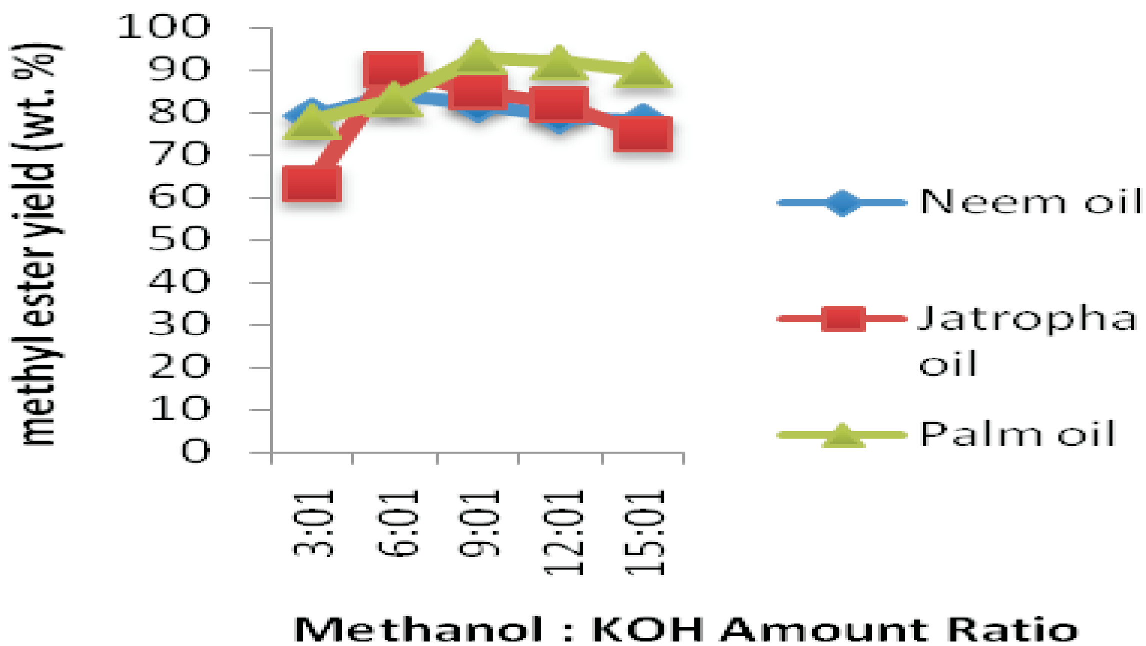


**Fig. 4 Effect of methanol concentration on methyl esters' yield**

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Journal of Energy Policy, Research and Development
Vol. 1, No1, pp (118-121), March, 2011. 

# AN OVERVIEW OF NUCLEAR ENERGY ACTIVITIES IN NIGERIA

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## ABSTRACT

This paper highlights an overview of nuclear energy activities in Nigeria from independence in 1960 to date. The introduction, energy in all its ramification as part of the landscape of national development was presented. A detailed discussion of historical developments of nuclear energy activities with emphasis on the quest by the country to join the race for peaceful uses of nuclear science and technology is presented. Furthermore, the current status of current nuclear energy acitivities beginning with the non-power applications and the current zest to add nuclear power to the energy mix of Nigeria are enumerated. In conclusion, solutions are proferred to problems slowing down the advancement of nuclear technology in the country.

## 1.0 INTRODUCTION

Since the dawn of the industrial age, the ability to harness and use different forms of energy has transformed living conditions for billions of people, allowing them to enjoy a level of comfort and mobility unprecedented in human history and freeing them to perform even more productive tasks. For most of the last 200 years, steady growth in energy consumption has been closely tied to rising levels of prosperity and economic opportunity in much of the world.

Energy has a major impact on every aspect of our socio-economic life. It plays a vital role in the economic, social and political development of our nation. Inadequate supply of energy restricts socio-economic activities, limits economic growth and adversely affects the quality of life.

Improvements in standards of living are manifested in increased food production, increased industrial output, the provision of efficient transportation, adequate shelter, healthcare and other human services. These will require increased energy consumption. Thus, our future energy requirements will continue to grow with increase in living standards, industrialization and a host of other socio-economic factors.

In elementary physics, energy is defined as the capacity to do work. This means that inadequate supply or lack of energy will invariably translate to diminshed or lack of capacity to do work. In the physical sense, energy appears as mechanical, thermal, chemical, electrical, nuclear among others. The quest by man to utilize the enormous energy in the nucleus of atom began with the discovery of the neutron in 1932 by Chadwick as a very powerful projectile for exploring the nucleus. Nuclear fission was later discovered through the analysis of the end products of neutron-induced reactions. This discovery opened up the prospect of obtaining limitless energy from the nucleus of uranium and thus the quest for the technology to exploit this new source of energy began in earnest.

In the early days, soon after the first critical assembly was operated by Enrico Fermi and others in 1942 at the University of Chicago, nuclear energy activities was dominated by the quest for military applications because of the fact that nuclear fission chain reactions had military significance. Today, the peaceful uses of nuclear energy are the main goals of all. This stems from the "Atoms for Peace" speech by the US President, Mr. Dwight Eisenhower while addressing the 470$^{th}$ plenary meeting of UN general assembly in December, 1953, after the World War II. To attempt a discussion of the military option is risky because of the emotional nature of subject and the impossibility of doing justice to the complex problems involved. Nevertheless, a complete neglect of the military issue in this paper does not imply that nuclear technology is entirely benign. This overview of nuclear activities in Nigeria will include the historical developments of the nuclear science and technology in the country and the status of progress made by stakeholder organizations with regards to the introduction of nuclear option in Nigeria's energy mix.

## 2.0 HISTORICAL DEVELOPMENTS

Nigeria took the first step in 1976 towards a coordinated and orderly application of nuclear energy in the country, when the Nigeria Atomic Energy Commission (NAEC) was created by Act 46 as a specialized agency to promote and streamline its implementation. However, NAEC was not activated and inaugurated until the year 2006. Also in 1976, two nuclear research centres, namely, Centre for Energy Research and Training (CERT), and Centre for Energy Research and Development (CERD) were established in Zaria and Ile-Ife, respectively. The two university-based research centres were later brought under the supervision of the Energy Commission of Nigeria (ECN). These two centres alongside the Nuclear Technology Centre (NTC) at Sheda Science and Technology Complex (SHESTCO), Abuja, were eventually transferred to NAEC in 2007. SHESTCO was established in 1991, with the mandate to, among others, conduct research for the development of nuclear energy. These research centres maintain various nuclear research and development facilities including neutron generators, isotopic neutron sources, X-ray Fluorescence facilities, a nuclear research reactor, a gamma irradiation facility and a linear accelerator. These facilities have impacted positively on the socio-economic development of the nation and contributed significantly in creating and promoting awareness in the peaceful uses of nuclear energy in the country. In order to ensure proper regulation and control in the nuclear technology sub-sector, the Nigerian Nuclear Regulatory Authority (NNRA) was established by Act 19 of 1995 and inaugurated in 2001. To address the environmental challenges (including those that may come with nuclear technology and other human activities) the National Environmental Standards and Regulations Enforcement Agency (NESREA) formerly known as Federal Environmental Protection Agency (FEPA), was established as a parastatal of the Federal Ministry of Environment.

Prior to the 1976 date, Nigeria became aware of the threats of nuclear radiation and so had monitored the French nuclear tests in Sahara desert in the early 1960's. To do this, the Federal Government had to set up the Federal Radiation Panel in 1961 and the Federal Radiation Protection Service (FRPS) at the University of Ibadan (UI) in 1964. This same year, Nigeria also became a member of the International Atomic Energy Agency (IAEA), thus opening up an avenue for obtaining technical assistance in the nuclear field and also signaling the country's interest in joining the race for the peaceful uses of nuclear energy. Before these events, Nigeria has had pockets of individuals and institutions applying one form of nuclear technology or the other, in their research and professional activities. Radium needles and X-ray machines have been used in medical application by some hospitals across the country. Similarly, caesium (Cs) sources were being used for cancer treatment as far back as 1960 at the University College Hospital (UCH), Ibadan. A close evaluation of our experience indicates that whatever progress had been made could have been many more times greater than it is if there had been able leadership, proper planning and coordination in our quest for peaceful applications of nuclear technology.

## 3.0 CURRENT STATUS OF NUCLEAR ENERGY ACTIVITIES

As contained in the National Energy Policy (NEP) "the nation shall pursue the exploitation of nuclear energy for peaceful purposes". Therefore, in addition to the generation of electricity, nuclear energy finds many other peaceful applications. In fact, it had been used in the country for decades for various other applications in health care delivery system, petroleum industry, agriculture, food preservation, animal husbandry, water resources management, pest control, industry, materials analysis, and mineral exploration.

These non power applications of nuclear

energy currently dominate the present activities of the nuclear industry coordinated by NAEC. The three nuclear energy research Centres operate under the supervision of NAEC and are involved in manpower training and capacity building. Two of the Centres are university-based, one at the Obafemi Awolowo University, Ile-Ife (i.e. the Centre for Energy Research and Development, CERD) and the other at the Ahmadu Bello University, Zaria (i.e. Centre for Energy Research and Training, (CERT), respectively. The third Centre was established in 1991 at Sheda Science and Technology Complex (SHESTCO) in Abuja. The first nuclear research reactor in the country is sited at CERT, Zaria and has been in operation since 2004. It is a 30 kW nuclear research reactor, the Miniature Neutron Source Reactor (MNSR) and codenamed **N**igeria **R**esearch **R**eactor**-1** (NIRR-1). In addition to this, a 1.7 MV TANDEM, charged particle accelerator is in operation at CERD, Ile-Ife and was commissioned in 2008. These facilities are complemented by the Gamma Irradiation Facility currently in operation at SHESTCO, Abuja. Recently, NAEC has created two additional nuclear energy research centres at the Universities of PortHarcourt and Maiduguri, respectively. In the area of nuclear regulation, NNRA became operational in 2001. It was established to develop and enforce all the needed guidelines on radiation protection, nuclear safety, nuclear security and safeguards. With regards to the power applications of nuclear energy activities in Nigeria, the Federal Republic of Nigeria has shown the political will to add nuclear to energy mix of the country through the activation of NAEC in 2006. This came as result of the visit of immediate past Director-General of the IAEA, Dr Mohammed El-Baradei to CERT, Zaria in 2005, following the successful commissioning of NIRR-1. The former President, Chief Olusegun Obasanjo requested the technical assistance of the IAEA for the country in her quest to add nuclear to the energy base of Nigeria. NAEC is the National Focal Point for the promotion and development of atomic energy and charged with the primary responsibility for nuclear power plant (NPP) programme implementation. In pursuant of the Federal Government's intention of adding nuclear to its energy mix, a National Road map, tagged the "Technical Framework for the Deployment of Nuclear Power Plants for Electricity Generation in Nigeria" and its "Strategic Implementation Plan" have been developed by NAEC and approved by Government for implementation. The technical framework is a three-phase plan, which is aimed at positioning Nigeria to generate electricity from nuclear reactors by the year 2020 with considerable national participation. The three phases are: (a) Manpower and infrastructure development; (b) Design certification, regulatory and licensing approvals; and (c) Construction and start-up. The programme is in the first phase with emphasis on the training of requisite human capital and the involvement of existing expertise in the implementation of the second phase. Some of the challenges confronting the programme are: Long-term national (political) commitment, and sustainability of programme over a gestation period of at least 20 years; Training of requisite restrictive manpower and long time required to build critical mass; Development of appropriate infrastructure needed to support the implementation of the programme; Development of requisite industrial capacity to gradually domesticate nuclear technology; Development of the requisite financing plan, catalyzed by Government, with the private sector as a partner; and Motivation and sustenance of the interest of the Nigerian Public to develop a positive attitude in the country, while maintaining the confidence of our partners.

## 4.0 CONCLUSION

For the past 10 to 15 years, the energy sectors in most developing countries have been in turmoil. Many of these countries including Nigeria have been attempting to restructure their energy sectors but are finding it difficult to implement reforms for a host of reasons, including the multiplicity of actions involved, which include changing perceptions of the relative roles of the market and Governments, and the baggage of accumulated policies of the past few decades—many of which may have made sense, when they were proposed but now impose unsustainable burdens. The provisions of the NEP with respect to nuclear energy sources are adequate for achieving sustainable development, if faithfully implemented. The needed infrastructures have been put in place but require strengthening through proper supervision and funding. The only way to ensure the attainment of Vision 20:2020 is to emulate the developed and fast growing economies of the world by mainstreaming energy planning into overall national plans. The deployment of nuclear power for electricity generation globally has achieved good degree of success and it is part of the energy mix of the leading economies in the world. Even disregarding the current "nuclear renaissance" in the world, the acute power shortage in Nigeria, nuclear is no longer an option but a necessity that must be added to the nation's energy mix in the medium and long term timelines. **Over the past 40 years, nuclear power has presented less risk to the public and workers than the other major sources of electricity generation (coal, gas and hydro). Regarding environmental impact, nuclear power is a clean source of energy with very low GHG emissions.** With the activation of NAEC in 2006, the Federal Government of Nigeria has launched a nuclear electricity programme, and has approved the roadmap for its implementation. Government should restructure the focal agencies for the prosecution of the national nuclear power programme vis-à-vis other stakeholder institutions and international development partners such as the IAEA. Nigeria has frittered away several years through bad leadership and lack of coordination when compared with smaller and poorer neighbouring countries whose nuclear activities are rated higher by the IAEA. It is not too late to put our acts together so as to enable our trained nuclear scientists contribute to the programme, for there is room for all to do so. This will fast track the manpower development programme and create the requisite enabling environment for the successful implementation of the nuclear energy programme of Nigeria in partnership with the private sector.

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# An Evaluation of Fiscal Regimes for the Nigerian Petroleum Industry Bill

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## ABSTRACT

Petroleum has been the mainstay of the Nigerian economy for the past four decades. As a result, government is constantly looking for ways to enhance the contribution of the sector to the national economy without jeopardizing the environment and the communities from which the oil is produced, while taking into consideration the interests of the investor. Thus, there is an ongoing debate in the legislature on a petroleum industry bill which is intended to reform the oil industry in Nigeria. The aspect of the bill that has generated most reactions is the fiscal regime provisions in the bill. The petroleum industry bill sponsored by government, proposes some reforms in the existing fiscal regimes which the international oil companies consider to be detrimental to their interests. This paper identifies the key areas of disagreements on the review of the fiscal regimes. It also examines the strengths and weaknesses of the positions of government and the international oil companies by adopting a discursive approach and using quantitative information from respectable and trusted sources. Some recommendations are then provided for the way forward.

## 1.0 INTRODUCTION

Nigeria depends heavily on petroleum (oil and gas), with the petroleum industry activities providing about 65% of total government revenue and 95% of export revenues (Thurber et al., 2010). The socio-economic and political development of Nigeria will continue to be largely determined by the future of this industry. As a result, government is constantly looking for ways to enhance the contribution of the sector to the national economy without jeopardizing the environment and the communities from which the oil is produced, while taking into consideration the interests of the investor. Thus, there is an ongoing debate in the legislature on a petroleum industry bill (PIB) which is intended to reform the oil industry in Nigeria.

The PIB proposes fundamental changes in the Nigeria's oil industry anchored on five major goals, namely, creation of new regulatory institutions, transformation of upstream contractual agreements, new fiscal regimes, downstream sector deregulation, government participation in the industry and transparency in contractual agreements. The PIB has drawn different emotions from the stakeholders since it came into the public domain. The aspect of the PIB that has generated most reactions is the fiscal regime provisions in the bill. Fiscal regimes are the provisions for the taxes and fees on the production of oil and gas to secure an income for the government and country.

The controversy surrounding the fiscal regime provisions for the PIB is understandable because the fiscal regime is the government's most important factor the international oil companies (IOCs) consider in determining the profitability of their investments.

Explaining the reasons behind the need to review the fiscal regimes, government through its minister of petroleum noted that "the production sharing contracts (PSCs) that were concluded in 1993 were rather bad deals for Nigeria from an international perspective. The royalties were zero percent (0%). The taxes included a generous tax credit that wiped out much of the tax to be collected. The profit oil shares to government were low compared to most other nations. Therefore, Nigeria collects much less for government under these contracts than other petroleum exporting nations. Therefore the PIB now includes much higher royalties and a new tax framework" (Rilwanu, 2009). This will create a strong basis for renegotiations of the existing unfavourable contracts. The goal is to ensure a fair share of the revenue to Nigeria comparable to other important oil exporting nations. But the IOCs in Nigeria say that government take is already one of the highest in the world (MPPIBD 2009), and that the sanctity of a contract signed close to two decades ago should be respected.

In view of these claims and counterclaims, this paper will attempt to examine the strengths and weaknesses of each side of the argument and assess the fiscal regimes in the PIB in comparison with the international best practices and suggest the way forward. The aim is to contribute to national discuss on the PIB towards the formulation of appropriate policies for the efficient development and growth of the Nigerian petroleum sector. The approach adopted is discursive and tries to expound on the principles and goals of the PIB to promote better understanding of the PIB, its overall objectives and the benefits derivable for the industry, investors and Nigeria in general. It is not intended to form an opinion on any aspect of the bill but to shed light on the fiscal regimes for the PSCs in the bill. After this introductory section, there are five other sections. Section 2 discusses PSC and the fiscal provisions in Nigeria prior to the PIB while Section 3 discusses the fiscal regimes in the PIB. Section 4 examines the arguments for and against the need to review the existing fiscal regimes in the PSCs. Section 5 provides some recommendations for the way forward while the conclusions are presented in Section 6.

## 2.0 PRODUCTION SHARING CONTRACTS IN NIGERIA

There are four different types of petroleum arrangements in the Nigerian oil industry. They are Joint Operating Agreement also known as Joint Venture (JV), Production Sharing Contract (PSC), Service Contract (SC), and Memorandum of Understanding (MOU). Each contractual agreement was developed in response to trends in the global oil and gas industry as well as the desire to tackle problems inherent in old arrangements. In 1991, a Memorandum of Understanding (MOU) was signed between the Nigerian National Petroleum Corporation (NNPC) representing the government, and the IOCs – Shell, Mobil, Chevron, Agip, Elf, and pan Ocean - with the aim of attracting more investments into the sector following the price collapse and the subsequent lull in prospectivity in the late 80s. The policy also guaranteed for the IOCs a minimum profit margin of $2.30/bbl after tax and royalties on the equity crude oil. With the shift, the IOCs were encouraged to embark on bullish exploration activities, which enabled Nigeria's crude oil reserves to move from 18.0 billion barrels to 22.0 billion barrels in 1992, barely a year after the policy decision was taken. The MOU contained inherent mechanisms for review in a way that both parties were left satisfied even when the dynamics of the economy such as inflation and exchange rates set in. This is why the MOU is reviewed to reflect prevailing economic realities. Similarly, the PSC was introduced in response to the funding problem faced under the JV as well as the desire to open up the frontier areas such as the inland basins and the deep / ultra deep waters for more foreign participation. There is no doubt that the fiscal regimes in the PSC concluded around that period were based on the experience of the immediate past with low oil prices and a lull in exploration and production and a very limited view of the future which could not anticipate the current high prices of oil. PSCs were first introduced in the Indonesian oil industry in 1966. After independence, nationalistic feelings were running high and foreign companies and their concessions became the target of increasing criticism and hostility. In response to this the government refused to grant new concessions. In order to overcome the subsequent stagnation in oil development, which was a disadvantage to both the country and the foreign firms, new petroleum legislation was brought in. PSCs were regarded as acceptable because government upholds national ownership of the resources. The major oil companies were initially opposed to this new contract form as they were reluctant to invest capital into an enterprise which they were not allowed to own or manage. More importantly, the IOCs did not want to establish a precedent which might then affect their concessions elsewhere. The first PSCs were therefore signed by independent IOCs who showed a greater willingness to compromise and accept terms that had been turned down by the majors. Furthermore, it was argued that the independents saw this as an opportunity to break the dominance of the big oil companies and gain access to high quality crude oil (Barnes 1995). Thus challenged, the major IOCs entered into PSCs and found that in reality the foreign firm usually manages and operates the oilfield directly. From Indonesia, PSCs spread globally to all oil-producing regions with the exception of Western Europe where only Malta offers this type of contract (Kirsten Bindemann, 1999). The petroleum fiscal regime at the inception of the oil industry in Nigeria was characterized by concessionary arrangements between the government and the IOCs, although Ashland Oil Company (now Addax Nigeria) had a PSC arrangement in 1973 with the Nigerian National Oil Company (NNOC). Under a concessionary system, the title to hydrocarbons passes to the investor at the borehole. The state receives royalties and taxes in compensation for the use of the resource by the investor. Title to and ownership of equipment and installation permanently affixed to the ground and/or destined for exploration and production of hydrocarbons generally passes to the state at the expiry, or termination, of the concession whichever is earlier. The investor is typically responsible for abandonment (Silvana, 2007). The establishment of the NNOC, now NNPC in 1971 provided the opportunity for government to participate in oil operations through joint venture (JV) operations with the IOCs. The government is a non-operator and holds 60% (apart from the JV with Shell where it holds 55%) in all its JV arrangements with the IOCs. This arrangement requires the government to provide funds on a yearly basis (cash call payments) for operations with the IOCs. The approach resulted in substantial drain on government resources which could have been channeled to more pressing needs. Moreover, the participation in operations exposed the government to the inherent risks associated with oil and gas exploration. In 1992, the extension of exploration activities into the deep offshore areas marked the introduction of PSCs arrangements between the NNPC and the IOCs. The adoption of PSCs by government was premised on its inability to partner alongside the IOCs based on the fact that deep offshore exploration and production requires significant capital investment and the prospect risks are very high. The PSC was used as a vehicle for achieving deep offshore exploration and production and increasing the country's crude oil reserve. By 2007, Statoil, Shell Nigeria Exploration and Production Company (SNEPCO), Esso, Elf, Nigerian Agip Exploration Limited, Addax, Conoco and Petrobras, Star Deep Water, Chevron, and Oranto Philips were operating the PSC in Nigeria. PSCs seek to attract multinational corporations willing to risk capital and to use their technological expertise to develop a country's reserves. The multinational corporation is conventionally referred to as the operator, and in the event of an unsuccessful discovery, the host government is insulated from the risks associated with the exploration. Although many oil producing countries have adopted PSC, no universal model or standard contract exists as countries over the years developed their own variations of the contract, but there are features common to all types PSCs. These are:

i. The contractor bears all costs of exploration and production without such costs being reimbursable if no find is made in the acreage;
ii. Cost is recoverable with crude oil in the event of commercial find with provisions made for tax oil to offset actual tax, royalty and concession rental due and payable / deductible in full in the year; and cost oil to reimburse

the contractor for capital investments and operating costs.

iii. Profit oil - the balance after deduction of tax oil and cost oil, which is to be shared between the NNPC and the contractor in an agreed proportion.

In Nigeria, government take is classified into two broad categories: pre- production and post – production payments (Omorogbe 2005; Annan, 2010). The pre-production payments are a feature of the PSCs and service contracts and they allow the government to earn some revenue even before any discovery has been made. These include bidding fees, signature bonus, and surface / rental fees. Pre-production payments are dependent on the deposits that the company expects to find and can be substantial. In the early 1990s, the PSCs contractors paid signature bonus of $1million each. In the 1999 PSCs the contractors were subject to $20 million while the signature bonus for the post-2000 PSCs was $30 million each. The largest signature bonus of $210 million was paid by Shell Nigeria Ultra Deep (Omorogbe, 2005).

Post-production payments consist of payments after commercial production and they include value added tax, royalty, rent, production bonus, education tax, Niger Delta Development Commission levy, petroleum profits tax and profit oil (Annan, 2010). Royalties are volume- based, vary with the water depth and the current figures are shown in Table 1. With regard to profit oil split, all payments are expressed in terms of proportions of cumulative or daily oil production and usually, greater proportions are given to the operators during low oil prices. This system is conventionally referred to as production based sliding scale. Alternatively, the profit split could be based on an R-factor (ratio of revenue to expenses) formula or rate of return (RoR) sliding scale. Daniel (2008) observed that a significant difference exists between the production based sliding scale approach and the R-factor / RoR model in that the former has no effect on government take when price increases while government take progresses with increase in oil price in the R-factor / RoR model. For the post-2000 PSCs in Nigeria, the percentages are as shown in Table 2.

Oboarenegbe (2011) viewed host government and investor agreements as a function of country proven reserves and exploration and production costs. In this regard, he posited that where reserves are large with medium exploration costs, countries would opt for PSCs arrangements. Countries in this category include Nigeria, Kazakhstan and Oman. Other West African countries that have embraced PSC models include Angola and Equatorial Guinea. Although PSCs have enjoyed wide appeal by oil producing countries, concessionary systems are still predominant in oil producing industrial countries like the United Kingdom, United States and Norway.

## 3.0 FISCAL PROVISIONS FOR THE PETROLEUM INDUSTRY BILL

From an historical perspective, the PIB is the idea of the Oil and Gas Implementation Committee (OGIC) inaugurated by the government in April 2000. The draft bill by the OGIC was subsequently subjected to further review and amendments by an Inter-agency Committee comprising the NNPC, Ministries of Petroleum Resources, Finance, Justice, Department of Petroleum Resources (DPR), Federal Inland Revenue Service (FIRS), the Revenue Mobilisation Allocation and Fiscal Commission (RMAFC), and the Nigeria Extractive Industry Transparency Initiative (NEITI). The changes introduced by the inter-agency team proposed a restructuring of the regulatory framework for the oil industry into separate regulators for the upstream, midstream and downstream sectors, introduced fiscal changes for the upstream, provisions for gas utilizations, refining/downstream sector reforms and replaced the joint venture (JV) agreements between the NNPC and the producing companies which cover most of Nigeria's onshore and shallow-water fields with the incorporated joint ventures (IJVs). The IJVs as legal entities will be capable of raising loans commercially and repay them from generated income. As a result, the IJVs will operate independent of government cash call obligations, ensuring an end to the recurrent defaults of NNPC to its cash call commitments. A key benefit for an oil-producing country is the government revenue that is generated. It is therefore critical that the fiscal regime be designed to secure maximum revenue for the government, while still providing investors with sufficient incentive to undertake exploration and development. In seeking to achieve this objective, fiscal regimes for oil tend to differ from those for non-resource sectors due to the presence of resource rents, that is, surplus revenues from an oil field after the payment of all costs, including an investor's risk-adjusted required return on investment. Since rent is pure surplus, it can be taxed without creating distortions. Furthermore, since oil, the source of the rent is an exhaustible natural resource that belongs to all citizens of a country; there is added pressure on the government to secure the rent for the benefit of the country as a whole.

With country's objective of maximizing revenue and the shortcomings of the previous agreements, the PIB introduced higher royalties and increased government take. The proposed royalties which are based on an aggregate of the royalties applied for production rate and oil prices are also differentiated for oil and gas. Productions in onshore fields below 2,000 barrels per day (b/d) attract 5% royalty rate and rising to 25% for production exceeding 5,000 b/d. The shallow water areas attract 5% on up to 5,000 b/d ranging to 25% on production over 50,000 b/d while deepwater attract 5% on production up to 25,000 b/d and above 50,000 b/d attracts 25%. The price-based royalty ranges on an incremental basis from 0% to 25% starting at $70 bbl with a price cap at $150. Therefore, in case of deep water fields and high oil prices, the maximum royalty accruing to Nigerian government will be 50%. This is certainly a mechanism for the government to capture windfall profits and increase government take on profitable fields front-end.

Similar changes in government take were introduced for the PSC. The limit for cost recovery is fixed at 80% of gross production and therefore reducing the 100% cost recovery provided under the 1993 PSCs. Also, the PIB terms substitutes the profit oil split on sliding scale basis in contrast to the 1993 PSCs giving the oil companies 80% share of profit oil for the first 350m barrels of production with declining share as cumulative production increases. The same applies to the 2005 PSCs using the R-Factor with the initial company share of 70% profit oil split. The two layers of tax introduced under the PIB, namely the Nigerian Hydrocarbons Tax (NHT) and Companies Income Tax (CIT) are applicable to both JV and PSC operations. NHT replaces the Petroleum Profit Tax (PPT) and is set at 50% for JV, 50% for gas and 30% for PSC while the CIT is introduced for all oil companies at the rate of 30% on net profits. A minimum of 10% withholding tax on dividends and education tax of 2% on revenue existing under the current fiscal regime is retained (Humphrey, 2010).

The PIB terms streamlined the NHT by abolishing the investment tax credits. It proposes to disallow interests expense/financing charges and imposes an 80% limit on expenses incurred outside Nigeria for tax deductibility while introducing benchmarking, verification and approval of all costs for tax deduction purposes. The cost benchmarking would be conducted by the regulatory institutions or the National Oil Company (NOC) and the verification and approval process conducted by the FIRS (Humphrey, 2010).

## 4.0 ARGUMENTS FOR AND AGAINST RENEGOTIATIONS

The decision to renegotiate petroleum contracts in the deep offshore PSCs is not unique to Nigeria. The unprecedented increase in oil prices in recent times has prompted many oil producing countries to revisit their oil contracts with the IOCs operating in their countries with a view of reflecting current market trends (Oboarenegbe, 2011). The argument by the Nigerian government is based on the fact that majority of these contracts were signed in the early nineties when crude oil price was closer to US$20 per barrel and the cost of exploring in frontier deep offshore was very high. The early deep offshore PSCs in Nigeria were based on a production sliding scale which analysts have argued is not an effective proxy of project profitability, hence the resultant profit split under a production based sliding scale inevitably results in minimum impact of increasing crude oil prices on government take (Oboarenegbe, 2011). Humphrey (2010) also observed that the Nigerian fiscal terms are currently lenient compared to its peers, particularly the countries with the same geological character. For instance, Libya has 93% allowances and the petroleum investment allowance (PIA) uplift on capital expenditures for existing arrangements and replaced them with allowances for small oil fields and new gas finds. Furthermore government take in UAE Abu Dhabi is on an average of 94%. Recent trends in global fiscal terms especially in this era of rising oil prices have built-in mechanisms of increased government share in windfall prices through increased royalty/taxes and linkages of royalty/tax rates to prevailing prices to ensure automatic adjustment of government share to price increases.

Undoubtedly, the tax changes would instigate an increased government take from an average of 73% to a projected 82% under the PIB terms. This calculation is derived on projections of a mid-size deepwater oil field with production of around 50 million barrels a year and oil price of US$75bbl. Therefore, the groundswell of opposition to the PIB is not farfetched since the existing arrangements have put the oil companies in advantage positions of reaping greater share from higher production and current high oil prices.

The crux of opposition to the PIB is that the IOCs see government take as already being too high and that it will create a harsh environment that would materially change the economics of the existing and new operations particularly in the deepwater regions. In their assessment of government take in the existing and future planned portfolios of deepwater projects, in comparison with other countries, they gave United Kingdom - 55%, Brazil – 60%, Indonesia – 74%, Norway – 74%, Angola – 76% and Nigeria Inter-agency proposal – 89% (MPPIBD 2009). The IOCs cite the high-cost nature and the complex dynamics of upstream economics, particularly of deep water fields with its high risk frontier explorations as weighted factors in investment decisions for the oil companies. These scenarios are not any different with the Nigerian environment in addition to its peculiar challenges such as the security situation in the Niger Delta, underfunding of JVs and global escalating cost basis. Moreover, the IOCs demand that the sanctity of a contract agreement signed about twenty years ago should be maintained. However, NNPC data shows that government take would increase from the current 42% to 70% whereas the world average is 75% as against the figures provided by the IOCs. Even Ghana that is just starting its petroleum industry has government take of 80% (Okonji, 2011).

## 5.0 DISCUSSION ON RENEGOTIATION OF CONTRACTUAL TERMS

During the 1980s and 1990s oil companies had difficult time making money exploring for hydrocarbons. At the same time most governments were dissatisfied with the level of exploration and development activity in their countries (Daniel, 2008). Therefore, many oil producing countries crafted incentives to encourage the IOCs to invest in exploration and production of oil and gas in their countries. Hence, much of today's petroleum fiscal systems had their inspiration from the era of low oil price of around US$20 per barrel. The current high oil prices were not anticipated in the design of the fiscal terms. This is why there has been “a great deal of smoke and heat and very little light” (Asiodu, 1993) about the renegotiation of the contracts and fiscal and legislative actions these last few years.

As a matter of fact, the issue of petroleum contract renegotiation has become a recurring concern between host governments and IOCs since quadrupling of oil prices in the early seventies. Although a great many parameters determine the nature of the contracts, such as the maturity of the oil sector, the fiscal regime, import and export dependency, geological aspects, cost and the regulatory framework, the major factor necessitating contract renegotiation has been fiscal terms. Perceived excess profits particularly during periods of high crude oil prices and declining exploration costs are key drivers accentuating contract renegotiations by host governments. The work of Oboarenegbe (2011,) describes this host government / investor relationship as the obsolescing bargain case. In this regard, he noted that "time brings change in perspective to bargaining relations between government and foreign corporations. At the outset of petroleum operations, the contractor could be regarded as the 'protagonist' but once commercial discovery is made, bargaining power shifts to the host government. Securing long term fiscal stability is a key priority to any international investor. This strategy would enable the investor determine the profitability of a particular project *from the onset* with a view of informing its shareholders about likely dividends. Investors would be reluctant to invest in countries with significant high contractual and political risks.

The relationship between host governments and IOCs is governed by contracts most times drafted within the framework of a petroleum law. Kirsten (1999) and Omorogbe (2005) observed that there are instances when these agreements were entered upon at a time when the host country was politically or economically weak, or was badly advised, the consequence being a contract that put the host country at a clear disadvantage. Later, the country, usually under a new political regime, realizes the problem and seeks renegotiations. But some companies (if not all), reject the idea of renegotiation, or complain loudly about its unfairness. Curtis (2010) also noted that there could be features of the oil industry that make contract renegotiations either inevitable or desirable. These are the long-term nature of oil upstream licenses or agreements, the sharp volatility of oil prices, and the vital importance of oil revenues for the exporting countries. And circumstances can change radically at least once if not several times over the contractual periods that usually extend over 20 to 25 years. The sharp volatility of prices is an important change of economic circumstances for the simple reason that conditions agreed upon when oil prices were low become unacceptable when prices move to significantly higher level. Host countries that have taken measures to renegotiate their petroleum contracts in recent time include Algeria, Bolivia, Canada, China, Ecuador, Kazakshstan and Venezuela, all of which imposed new taxes and royalties on production, exports or windfall profits (Curtis, 2010). In the case of Canada, royalty and tax treatment regime extended to all conventional oil, natural gas and oil sands production were reviewed in 2009 in response to rising oil prices (André, 2009). The government of Trinidad and Tobago also noted that oil exploration and development projects are characterized by large capital investments, long lead times, incomplete information, and in most cases significant differences in the abilities of the parties to bear the risks involved in the venture. Thus contracts are potentially unstable and one or both signatories may want to renegotiate at some point in time Trinidad and Tobago (2010). Thus the country started renegotiation of its petroleum contracts in 2010.

One of the world's best known renegotiations of the last few years involved the world's largest PSC, the one covering the Kashagan field in Kazakhstan. There the heart of the problem was the concept of cost recovery, under which a large percentage of production, known as cost oil is allocated off the top to the contractors to recover their costs. In the case of Kazakshstan, that percentage was 80 percent. After allocation of that 80%, the remaining production, known as profit oil, was allocated initially 90% to the contractor and 10% to the State, a ratio that was eventually supposed to change in favour of the State based on a set of complicated triggers set forth in the agreement. Until then, the contractor would continue to receive 80% of the cost oil and 90% of the profit oil, or 98% of the total production.

Despite what many feel is a typical alignment of interests in a contract including such cost recovery provisions, experience shows that this structure is a recipe for disaster, and that is exactly what happened in Kazakshstan. Overall costs of the project increased by more than 100 billion dollars, and production, originally scheduled to start in 2005 or 2006 is now scheduled for 2012. The net result was that in the world's largest discovery in recent times, which is expected to produce 1.5 million barrels per day, the state would have received a grand total of 2% of the oil produced for at least the first decade of production, not including the relatively small participation of a subsidiary of the national oil company in the contractor consortium. The government of Kazakshstan it an unacceptable situation, which most people with knowledge of the facts fully recognized. In the renegotiation, the national oil company's subsidiary doubled its stake in the project, a new priority share was allotted to government off the top, and new cost and schedule control mechanisms were introduced to help guard against future cost increases and delays (Curtis, 2010).

Crafting agreements with the right combination of stability and progressivity is one of the industry's important challenges (Daniel, 2008). While the host government may exercise the right to renegotiate its contractual terms, the oil rich developing countries in need of foreign investments stand the risk of losing development of their oil reserves as a result of frequent contract renegotiations. The oil companies are in business to make money and hence are constantly in search of where their returns will be highest. In this regard, Shell's Director of Projects and Technology has this to say: "in the upstream, we have shifted our portfolio more to Organization for Economic Cooperation and Development (OECD) countries to balance the risk in the overall portfolio. We have clearly seen that over the past few years as oil prices rose, returns in the non-OECD countries deteriorated compared with those in the OECD. Our upstream strategy is underpinned by a very active and aggressive exploration approach" (Matthias, 2011). Alfred (*Alfred, 2004) compared profitability from a number of oil producing countries to underscore the importance of fiscal regimes in the upstream project economics. The result summarized in Fig. 1, shows that* a 25 million barrels field in Ireland gives the same profit after tax for the oil company as a 104 million barrels field in Nigeria and the IOCs have access to such analysis. Hence, there is no doubt that investments in the sector by overseas companies will be reduced.

An independent assessment based on the deterministic and probabilistic modelling of the impact of the fiscal provisions in the PIB on offshore exploration and production economics and system measures shows that the government take is 89% in the deterministic case and for the stochastic case at 50 per cent confidence, government take ranges from 87% to 90% with the most likely being 88% (Iledare, 2010).

## 6.0 CONCLUSION

Petroleum has a major impact on every aspect of our socio-economic life. It plays a vital role in the economic, social and political development of the nation. Thus the current debate on the PIB deserves extensive analysis by all in order to arrive at positions that will be most agreeable to stakeholders in balancing government objective of maximizing revenue and IOCs objective of maximizing present value of their income from the exploration and production activities.

The PIB came about in order to improve on the general efficiency of the petroleum sector. The present legislations and especially the fiscal regimes are no longer in tune with the current realities of Nigeria and international best practices in the oil and gas industry. The agreements were negotiated when oil prices were very low compared with current oil prices. Given that petroleum business is an international subject, experts in the field are of the opinion that petroleum contracts could indeed be renegotiated. Therefore, the IOCs need to cooperate with government to find a lasting solution to the problem.

However, in renegotiation, government should also bear in mind that ventures in the petroleum sector are of a high risk nature in the physical, commercial and political sense as it is difficult to determine in advance the existence, extent and quality of the reserves as well as production costs and the future price in the world market. Profitability is not assured even though the IOCs are in business to make profit. Hence care should be taken so the review of the fiscal regimes does not become counterproductive by reducing investment inflows into the sector and subsequently jeopardize the socio-economic development aspirations of the country. The challenge of an efficient fiscal system is to induce maximum effort from the oil companies while ensuring that the government is adequately compensated.

**Table 1: Royalties Payment in Nigeria**

| S/No. | Location | Water Depth, metres | Rate, % |
|---|---|---|---|
| 1. | Onshore | 0 | 20 |
| 2. | Offshore | 0 - 100 | 18.5 |
| 3. | Offshore | 100 - 200 | 16.67 |
| 4. | Offshore | 201 - 500 | 12 |
| 5. | Offshore | 501 - 800 | 8 |
| 6. | Offshore | 801 - 1000 | 4 |
| 7. | Offshore | > 1000 | 0% |

*Sources: FGN (1999), Omorogbe (2005)*

**Table 2: Profit Oil Percentages**

| S/No. | Cumulative Production (million barrels) from | Contractor | Government |
|---|---|---|---|
| 1. | 0 - 350 | 70 | 30 |
| 2. | 351 - 750 | 65 | 35 |
| 3. | 751 - 1000 | 52.5 | 47.5 |
| 4. | 1001 - 1500 | 45 | 55 |
| 5. | 1501 - 2000 | 35 | 65 |
| 6. | > 2000 | Negotiable | Negotiable |

*Source: Omorogbe (2005)*

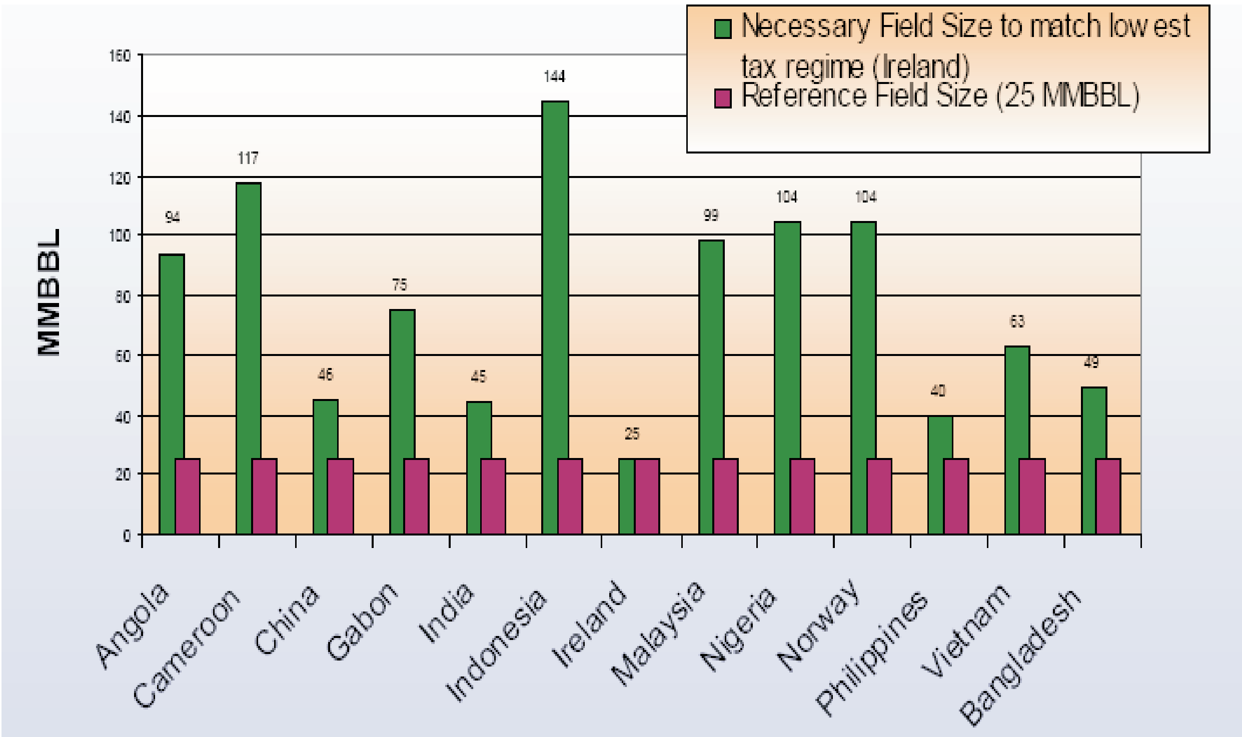


Fig. 1: Value of Discovery after Tax
*Source: Alfred Kjemperud, 2004*

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