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# The Impact of Climate Change on Renewable Energy Resources and Production Systems In Nigeria

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**Abstract**

This paper discusses the potential effects of climate change on some of the renewable energy resources and production systems in Nigeria with emphasis on hydro, solar, biomass, wind energy systems. Nigeria faces a unique and challenging situation with respect to energy for sustainable development. Climate change has environmental and socio economic consequence for Nigeria whose economy is highly dependent on fossil fuels which indirectly is the main cause of climate change. Changes in precipitation pattern affect energy generation and distribution from hydropower dams and crop farms for bio-fuel production. Higher ambient and surface water temperatures contribute to increased intensity of weather related events. Also energy production from solar energy systems and biological productivity are related to temperature. With renewable technologies inherently reliant on climate, changes will result among other things in altering the availability of natural energy resources, changes in the quantity and timing of renewable resource extraction potential and changes in the operational performance of energy production systems. It is anticipated that new findings may help in the valuation of renewable energy technologies and hence help in energy polices and decision making processes.

**Keywords:** Climate Change, Renewable Energy, Fossil Fuels, Solar Radiation, Hydropower

## 1.0 Introduction

Most recently, climate change has become more threatening not only to the socio-economic development of a nation but to the totality of human existence. Human and industrialization activities have in the last 100 years contributed to an increase in the concentration of greenhouse gases in the atmosphere leading to the enhanced greenhouse effect (Chris, 2008), which in turn has resulted in climate change. Climate change which is a change in the long term weather patterns that characterizes a region, is no doubt the most important and complex environmental global issue currently. There is a consensus that fossil fuel based energy production and use are the main sources of carbon dioxide and other greenhouse gases emissions (Contreras and de Cuba, 2008). The discovery of greenhouse effect which is the process by which the presence of an atmosphere acts to raise the surface temperature of a planet could be credited to Jean Baptise-Fourier. He did establish that a natural mix of certain greenhouse gases reside in the atmosphere which allow the short-wave radiation from the sun to penetrate the atmosphere, but absorb the lower wavelength energy which is re-radiated from the Earth's surface (Contreras and de Cuba, 2008). Because these greenhouse gases (GHG) are good absorbers of heat radiation coming from the Earth's surface, they act like a blanket over the Earth's surface, keeping it warmer than it otherwise would be. Enhanced greenhouse effect, on the other hand, is not natural. It refers to the changes in the earth's radiation balance due to the anthropogenic accumulation in the atmosphere of radiatively active greenhouse gases (Ikeme, 2008). In addition to carbon dioxide, other greenhouse gases include water vapour, methane, nitrous oxides, tropospheric ozone and chlorofluorocarbons. Their effect is to accelerate the warming effect beyond acceptable levels. It is this enhanced greenhouse effect due to human activities and other external forcing like solar variability, astronomical effects, tectonic processes and volcanic eruptions that result in climate change. It is the present effect and the future foreseeable effect of increased accumulation of these gases in the atmosphere that prompted the United Nations General Assembly to establish in 1990, the Inter-

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governmental Negotiating Committee, INC that drafted, negotiated and subsequently adopted the United Nations Framework Convention on Climate Change (UNFCCC) on 9$^{th}$ May 1992 (IPCC, 2007a; 2007b). Article (1) of that convention defined climate change as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to the natural variability observed over comparable time periods. This implied that climate system can vary naturally and when amplified becomes a change.

Renewable Energy (RE), an energy source that can be replenished naturally in a short period of time, depends directly on ambient natural resources such as hydrological resources, wind patterns and intensity, and solar radiation. Hence, RE sources is likely to be more sensitive to climate variability than fossil fuel or nuclear energy systems that rely on geological stores. RE systems are also vulnerable to damage from extreme weather events. At the same time the use of renewable energy resources and systems has long been identified as one of the major panacea for climate change (IPCC, 2001). Much has not been done on the effect climate change may have on renewable energy resources and production systems especially in Nigeria. The focus currently by international and local researchers is on how to drive the energy sector towards the use of renewable energy which is relatively cheaper, cleaner and environmentally friendly. Currently, action to stem the emission of greenhouse gases as encapsulated in the Kyoto protocol is restricted to the developed countries or Annex 1 countries. This requires the so-called Annex 1 countries to cut their greenhouse gas emissions by 5% compared to 1990 levels by the period between 2008 and 2012. Nigeria which belongs to the non-Annex 1 countries is not required to take any abatement action now; rather the impact of global warming on Nigeria for which we are concerned in this paper stems from the threat to Nigeria's energy sector, in particular the renewable energy resources and the entire economy as a whole. Nigeria stands to suffer income losses when the global community begins to substitute renewable energy alternatives for fossil fuels. Given the exclusive reliance on fossil fuels for foreign exchange, the impact of the global shift away from fossil fuels is bound to cripple the Nigerian economy. As it stands, the Kyoto Protocol, if fully implemented, would lead to a dramatic loss of revenue for oil-exporting countries, as a result of a heavy reduction in the local and global demand for petroleum. Hence there is an urgent need for us to look critically into these RE alternatives by identifying the effects climate variability and change will have on these systems and resources and seek out ways of reducing or adapting to the change so that when the rest of the world moves away from fossil fuels we will not be left out in the cold. This paper will focus on the potential impact of this climate change on current RE availability and production systems in Nigeria. Section 2 deals with climate change in Nigeria as a country, section 3 dwells on the impact on renewable energy systems and finally section 4 concludes.

## 2.0 Climate Change In Nigeria

Nigeria lies between latitudes 4$^{0}$and 14$^{0}$ N and longitudes 3$^{0}$ and 15$^{0}$E (see Leong, 1971). The location, size of and characteristics relief in Nigeria gave rise to a variety of climates ranging from tropical rainforest along the coasts to the Sahel climate in the northern parts of the country. Annual rainfall is greater than 3500mm in the wet coastal area but less than 600mm in the Sahel region of the north western and north eastern parts (Sowunmi and Akintola, 2010). The mean maximum temperature in the far south is between 30$^{0}$C and 32$^{0}$C while in the north it is between 36$^{0}$C and 38$^{0}$C. However the mean minimum temperature is between 20$^{0}$C and 22$^{0}$C in the south and under 13$^{0}$C in the north which has a much higher annual range. The mean temperature for the country is between27$^{0}$C and 29$^{0}$C in the absences of altitudinal modifications (see Federal government of Nigeria, (FGN) 1997).

Based on IPCC (Intergovernmental Panel on Climate Change) projections, the humid tropical zone of southern Nigeria which is already too hot and too wet is expected to be characterized by increase in both precipitation (especially at the peak of the rainy season) and temperature. Also eleven of the years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850, see IPCC, 2007a). There may not be a clear consensus on the trend of rainfall in Nigeria. This is because some researchers have studied trends in both rainfall and temperature over some periods in various regions of the country and arrived at diverse conclusions. According to Adejuwon (2004), temperature increases of about 0.2$^0$C - 0.3$^0$C per decade have been observed in the various ecological zones of the country, while drought persistence has characterized the Sudan-Sahel regions, particularly since the 1960s. He continued by saying that for the tropically humid zones of Nigeria, precipitation would probably increase by approximately 2-3% for each degree rise in temperature and that for the very humid areas of the forest regions and south savanna areas, precipitation increase of about 5-20% may be expected. The rainfall trend over a period of 64years (1922-1985) was examined by Evans and Adejuwon (1994). He used data from 16 stations scattered over the country using the least square method and it was observed that with reference to annual rainfall, 75% of the station show a trend of decreasing rainfall which is more pronounced in the last 20 years. Ojonigu, Iguisi and Afolaya (2007) tested the rainfall trend using 50 years (1953-2002) data for four stations (Potiskum, Sokoto, Samaru Katsina) in the Sudan- Sahel zone of the country. The result of the test using 5 year and 10-year running mean showed that there was a decline in the annual rainfall in the zone from the mid 1960s to the mid 1990s, but that from the 1990s the trend would be an increase in the annual rainfall.

Ayoade (1970; 1973) analyzed trends in annual rainfall using least squares methods. He observed that over most parts of Nigeria there appears to be no significant overall trend in the annual total over the period between 1931 and 1960 apart from three stations; Onitsha, Abakaliki and Ikot Ekpene that showed a tendency towards significant downward trends. Later the same author observed that the annual totals in many parts of Nigeria were 30 percent below normal and that virtually the country as a whole had negative rainfall departure from normal. Gbujiro, Iso and Ediang (2005) studied energy production over Kainji Dam using monthly and annual values of some climate parameters and arrived at the conclusion that the annual rainfall for northwest Nigeria is decreasing at a rate of 2.7mm/yr with a mean value (799.3mm) while evaporation is increasing at a rate of 24mm/yr with a mean annual value 3991.8mm. Also that the average annual runoff for Kainji reservoir for the period 1951-2000 is 14508.4m$^3$/s while mean annual runoff was decreasing at a rate of 260m$^3$/s, the average energy generated from Kainji reservoir for the period was 2009.9MWh. Hydroelectric energy generated from Kainji according to Gbujiro, Iso and Ediang (2005), was observed to be decreasing at the rate of 2.4MWh/yr. The 1971-1973 drought resulted in a decrease in water availability both for agricultural purposes and water levels in all artificial lakes (dams) and natural lakes (like that of Chad) hence a reduction in their capacity for power and irrigation water supplies. Looking at the annual mean rainfall pattern for some cities in Figures 1 (a and b) for ten years (1990-2000). Using the least square polynomial regression method on the curves showed no significant correlation between the years and the quantity of annual rainfall except for Port Harcourt that gave a correlation coefficient of 0.537.

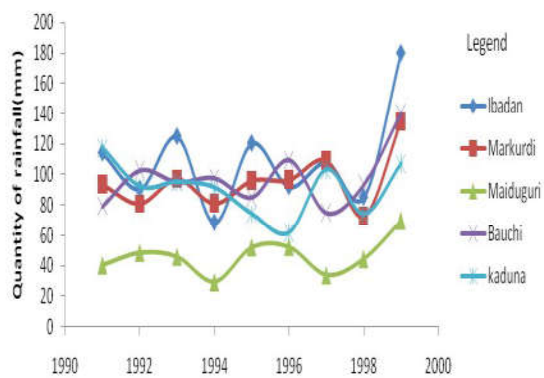


Figure 1a: Annual mean rainfall for some cities
(Source: National Bureau of Statistics Annual Book of Statistics 1999)

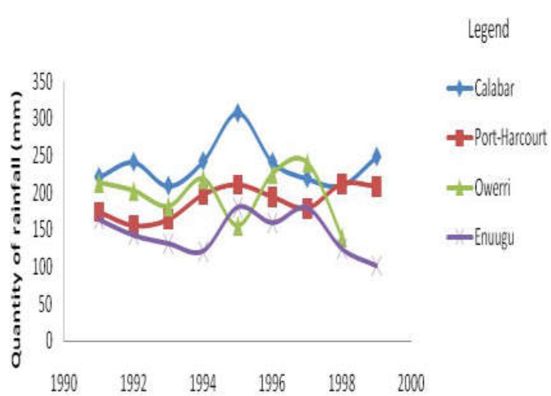


Figure 1b: Annual mean rainfall for some cities
(Source: National Bureau of Statistics Annual Book of Statistics 1999)

Figures 2 (a and b) shows the mean maximum temperature for nine years (1996-2004) for some cities and form the regression done on the data, there is no significant correlation between temperature and the years although the data is not enuogh to give a definintive conclusion. Nevertheless we will work on the general notion that the is a reduction and variability in the rainfall pattern and that the ambinet temperature has risen above normal.

## 3.0 Climate Change Impact On Renewable Energy Systems

The energy sector is vulnerable to the effects of climate change in several ways as many different aspects of the energy industry are directly affected by environmental and climatic conditions. Some of these interactions are given below;

- Seasonal and daily temperatures changes affect the timing of peak electricity demands and the size of the demand;
- Extended periods of drought lead to reduced water availability for hydropower generation;
- Changes in temperature and precipitation affect water availability for cooling power generators;
- Changes in cloud cover, temperature and pressure patterns directly affect wind and solar resources;
- Increased occurrence of blackouts may be observed as a result of higher electricity demand;
- Increased intensity and frequency of severe weather events impacts on energy infrastructure, for instance power plant, transmission lines, refineries, oil and gas drilling platforms. These weather related supply disruptions result in higher energy prices.

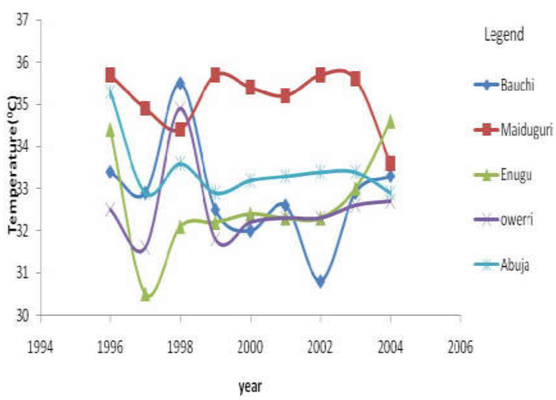


Figure 2a: Anuual mean maximum temperature for some cities

(Source: National Bureau of Statistics Annual Boof of Statistics 1999)

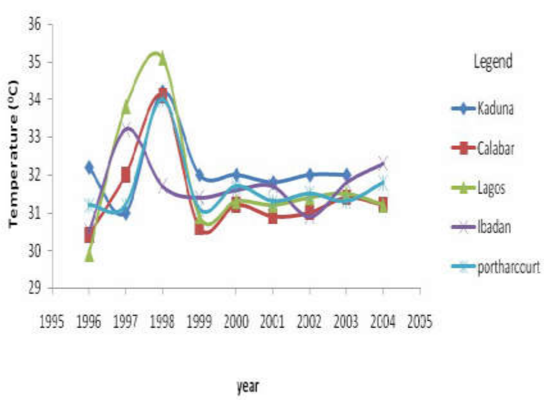


Figure 2b: Anuual mean maximum temperature for some cities

(Source: National Bureau of Statistics Annual Boof of Statistics 1999)

Beyond large hydropower, the current total contribution of renewable energy in Nigeria's electricity industry is about 35MW composed of 30MW small hydropower and 5MW of solar PV. This represents about 0.6% of total nominal electricity generating capacity in the country (see Federal Ministry of Power and Steel, 2006). Renewable energy technologies are dependent on climatic variables and patterns such as hydrological resources, wind patterns and solar radiation and they therefore tend to be very venerable to climate change and variability. If the hydrological cycle, the atmospheric conditions or the solar distributions changes, alterations in the availability of RE resources can be expected. Depending on the specific location and time a RE system is established, changes in wind, solar or hydro energy potential may determine the viability of these RE technologies. It has been said that to combat climate change, it is important to reduce energy related green house gas emissions. Hence renewable energy resources can be said to have a negligible effect on climate change while climate change can have a serious effect on RE technologies.

### 3.1 Effects of climate change on hydropower systems

In Nigeria, more than 3500MW of electricity is consumed in Nigeria 32% of which is from hydropower generation. Hydropower potential in

Nigeria which is located mainly in the rivers Niger and Benue and their tributaries has been estimated to be above 11,000MW with its generation from three major stations; Shiroro, Jebba and Kainji and other small, mini/micro hydropower stations (see Ismail, 2006). Hydropower is currently the only major renewable source contributing to energy supply and its future contribution is anticipated to increase significantly. However, the successful expansion of hydropower is dependent on the availability of the water resources and on its management. Hydroelectric power potential depends on stream flow which depends directly on precipitation, temperature levels and potential evapo-transpiration. Precipitation directly impacts runoff levels and stream flows which then determine the amount of water available for hydro electric generation. Changes in precipitation cycles due to climate change can alter river flow patterns resulting in longer periods of drought thus causing water levels to decrease and affecting hydro power generation capacity. Another potential consequence of altered river flow patterns is the increased incidence of elevated flow rates and flooding that exceed the safety margins of existing hydro plants. Statistical analysis of hydro-meteorological data of the Kainji dam done by Olofintoye and Adeyemo (2011) indicates an increased rain around the areas surrounding the dam. Although increased flow rate and flooding if timed and managed could lead to increased hydro power generation. For example, a shift in higher stream flow rates from dry to wet season (e.g., changes to less frequent rains but with higher quantities of rain at a particular moment) may increase hydropower generation more in the wet season than it is reduced in the dry season. Temperature fluctuations reduce the bearing capacity of the dams due to seepage pressure and concrete wall cracking (see Agunwanba, 1994). Random and unpredictable changes in climate affect electric power demand. In the short term, the predicted load pattern becomes unreliable and this poses a lot of problem to the system dispatch who may have to depend on personal intuition rather than on previous pattern. Higher relative humidity in the rainy season and greater frequency of severe electrical storms would subject power installation to greater risks. Load and reservoir inflow forecasts are usually based on historic records of observed loads and inflows. Significant changes in the trends of stream flows and load will invariably make historic data useless.

### 3.2 Effects of Climate Change on Biomass Energy and Biogas Production Systems

Biomass energy refers to the energy from biological systems such as wood and waste while biogas is the gas produced from anaerobic digestion of these biological systems and waste. Biomass resources in Nigeria can be identified as wood, forage grasses and shrubs, residues and wastes (forestry, agricultural, municipal and industrial) as well as aquatic biomass. The energy content of fuel wood that is being used is 6.0x $10^9$MJ out of which only 5% is gainfully utilized for cooking and other domestic uses (Sambo, 1992). For forage grasses and shrubs, estimates show that 200million tons of dry biomass can be obtained from them and this comes to 2.28x$10^6$MJ of energy. For crop residues and wastes, estimates of the 61.0million tons of dry biomass produced annually leave residue whose energy content approximate to 5.3x $100^{11}$MJ. Estimates made in 1985 gave the number of cattle, sheep and goat, horses and pigs as well as poultry birds as 166million. These produce 227,500 tons of waste daily which comes to 2.2x$10^9$MJ taking the calorific value of animal dung to be 9.8x$10^3$MJ/tonne. The animal residue can be converted to biogas and the 227500 tons becomes 5.36x$10^9$$m^3$ if the entire residue is placed inside a biogas digester. This quantity of biogas is 55 percent methane and has energy content of about 2.93x 1010kWh (see Sambo, 1992).

Rapid changes in climate will most likely alter the composition of ecosystems with some species benefiting while others unable to migrate or adapt fast enough may become extinct. Some plants respond better at higher $CO_2$ level while others do not. Hence, any alteration in the level of $CO_2$ will result in either positive or negative productivity in crop yield. Energy commission of Nigeria recently entered into partnership with Global Resources Limited to cultivate Jatropha. Jatropha is a plant whose seed when squeezed produces oil. This oil has similar characteristic with mineral oil and when put in diesel generator burns without any detriment. Jatropha is cheaper and has 80% less carbon emission. It has no sulphur and is non edible and therefore does not compete in the food chain. Ayinde et al. (2010) analyzed agricultural production and climate change in Nigeria using the Granger model and observed that the lowest yield which occurred in 1983 may be due to increase in foreign earning as a result of increased oil revenue while the drop in yield in 2001 was due mainly to climatic factors. Biomass energy is intrinsically tied to biological productivity because it is the plants residue that is used in the production of the energy and the animals whose wastes are used; feed on the biological plants hence any change in the biological productivity affects the biomass energy production. Since it is the simultaneous availability of water and sunlight that limits biological productivity, actual evapo-transpiration (AE) which is the amount of water entering the atmosphere from the soil and vegetation during a period of time is an environmental variable that can be used for the purpose of predicting biological productivity (see Adesina and Adejuwon, 1994). Adesina and Adejuwon (1994) arrived at equation (1) for computing net annual above ground productivity throughout the world

$$Log_{10}NAAP = (1.66 \pm 0.27)Logl0AE - (1.66 \pm 0.07) \quad ...1$$

where AE is the annual actual evapo- transpiration and NAAP is the net above ground productivity.

In order to establish the relationship between productivity and air temperature, Adesina and Adejuwon. (1994) used a method of least squares linear regression of the productivity on actual evapo-transpiration on the data obtained from ten meteorological stations in Nigeria and arrived at equation (2).

$$Y = 56793 - 2021.88x \quad ...2$$

where Y is the biological productivity and x is the annual mean air temperature.

The correlation coefficient is -0.79 which implied that the higher the temperature the lower the net annual productivity. Hence the average annual productivity might drop significantly given a change in temperature of about 0.5°C. Under a more arid condition, the problem will be greater and many plant species presently may become extinct. This will lead to a reduction in the biomass potential of the country.

### 3.3 Effects of climate change on wind energy systems

Wind is generated by the movement of air from regions of high pressure to regions of low pressure. Wind energy source arises from the differential heating of the earth's surface by solar radiation. It is estimated that between 1.5 to 2.5% of the global solar radiation received on the surface of the earth is converted to wind (see Ojosu and Salawu, 1990). However, Nigeria is located within low to moderate wind zone being within latitude $4^0$ and $14^0$N and longitude $3^0$ and $15^0$E this implies that for Nigeria, with an average daily insolation of 15MJ/m$^2$ wind energy availability is in the order of $1.1 \times 10^{11}$GJ/annum (Enibe, 1987). The proportion that can be transformed into useful work can only be determined by ground based measurements. Wind speeds in the southern parts of the country are generally weak (with values ranging from 1.4 to 3.0m/s except for coastal regions and hilly regions of the north with values as high as 5.12m/s (Okoro, Chukuni and Govender, 2011). Since wind flow is as a result of temperature gradient, if there is a change in the temperature gradient the wind patterns will equally change. Electricity generation is the most common use for wind energy. This is achieved by using the spinning of the wind blades to turn the armature in a generator located directly behind the blades. It has been shown that power (P) from wind per unit area is a function of wind speed and air density (Ojosu, 1989).

$$P = \frac{1}{2} \rho C_p \nu^3 A \quad ...3$$

where $\rho$ = air density, $C_p$ = power coefficient, $\upsilon$ = wind speed, A= area of wind turbine

In the study to establish the relationship between wind speed and air temperature, a method of least squares polynomial regression of wind speed on temperature was used on data obtained from Center for Basic Space Science CBSS; University of Nigeria, Nsukka. Using this approach, the following equations were derived for Abuja, Nsukka and Lagos respectively.

$$Y = 0.014x^2 - 0.759x + 0.254 \quad ...4$$

$$Y = 0.043x^2 - 2.200x + 28.62 \quad ...5$$

$$Y = 0.027x^2 - 1.416x + 18.27 \quad ...6$$

where Y = wind speed; x = temperature. The correlation coefficient for Abuja, Nsukka and Lagos are approximately 0.59, 0.51 and 0.92 respectively.

The positive correlation coefficient shows that the higher the temperature, the higher the wind speed hence the higher the power from wind. 0.5$^0$C rise in temperature will result in a substantial increase in the wind speed hence power derivable from wind. Wind speeds greater than the optimal for wind turbine also poses a problem. If the solar incidence decreases as predicted, a reduction in the wind speed will result.

### 3.4 Effects of climate change on solar energy systems

Solar radiation incident on the earth's surface varies in intensity with location, season, day of the month, time of the day, instantaneous cloud cover and other environmental factors. It cannot be over emphasized that Nigeria has an abundance of solar energy resource. It has been shown that Nigeria receives 5.08x$10^{12}$kwh of energy per day from the sun and if solar appliances with 5% efficiency are used to cover 11% of the country surface area then, 2.54 x $10^6$ MWh of electricity will be produced (see Federal Ministry of Power and Steel, 2006). Some of the solar energy systems already in use in Nigeria are solar photovoltaics which converts solar radiation directly to electricity and solar thermal systems. All PV Solar Panels are affected by heat and the hotter the solar panel, the lower the power output (see Wikipedia, 2011) - but how significant is this effect? Some experiments have been done to know the effect of temperature on solar PV panels. Oyegbade, Salami and Akande (2003) found that the conversion efficiency of the solar cell used in the fabrication of the panels was highest at 9.00am. The efficiency decreased with increase in the ambient temperature. The one done by renewable energy technologies in the United Kingdom to determine how significant the lowering of solar power output from solar panels are due to increased in temperature showed that the total power loss due to the increase in temperature was above 40% (see Renewable Energy UK, 2011). It was also shown by Brinkworth and Sandberg (2006) that there is a 0.5 efficiency loss with 1$^o$K rise in the solar cell temperature. As to be expected, an increase in solar flux should increase solar cell efficiency which has been shown empirically by Ettath, Obiefuna and Njar (2011) and Omubo-Pepple, Isreal-Cookey and Alamunokuma (2009). Another study predicts that a 2% decrease in solar radiation will decrease solar cell output by 6%. Anthropogenic sources of aerosols can also decrease average solar radiation especially on a localized basis. Solar thermal systems are also being impacted by temperature and solar radiation.

## 4.0 Conclusion

Climate change is increasingly being recognized as a phenomenon that whether human induced or not has an impact on people's lives. Renewable energy (RE) production is highly susceptible to climate change and variability. Hydropower is the most dominant of all the renewable energy resources in Nigeria although there is a great potential for biomass, wind and solar and climate change can be expected to have a significant effect on them. RE facilities are generally designed and placed based on historical climate data or to suit prevailing climate conditions without the consideration of future climate change in feasibility studies. If key energy stakeholders are not aware of climate change implications to the productivity or even the viability, of RE production systems, the ability of the country to supply reliable and affordable RE may be a mirage. Impacts on key energy resources substantially impact the cost competitiveness of these RE technologies due to changes in resource availability or variability and may even impede the planning and financing of new projects. This would have a significant effect on the overall economy of the nation. There is need for more research in this area to ascertain concretely the relationship between climate change and renewable energy resources and production systems. This will enable the government and energy decision makers to take the necessary actions so that that the country will not be left out when the developed countries switch completely to RE technologies.

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