ECONOMIC GROWTH RELATED ENERGY EFFICIENCY AND CARBON EMISSIONS BASED ON THE ENVIRONMENTAL KUZNET CURVE HYPOTHESIS

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ABSTRACT

The subject of connecting relationship between energy consumption and macro-economic variables linked with the quanta of continuous emissions provides a platform for informed decision making and is often performed using the theoretical environmental Kuznets. This study evaluates the relationship between economic growth, as reflected on the magnitude of the nation's gross domestic products and the accompanying carbon dioxide emissions using the environmental Kuznets curve (EKC) hypothesis. The trend of energy consumption pattern for the nation with respect to the energy carriers was utilised for the EKC evaluation and serves to present a holistic view of the emissions during the considered years. From the results obtained, a steady increase of emissions was observed from 29.09 million tCO_2 to 61.72 million tCO_2 as the years passed from 1980 to 2010, reflecting corresponding increase in the population, a factor that completely affect energy consumption; the pattern of consumption reflects the times, and the available mechanisms for energy conversion processes. Furthermore, from the model obtained with the available data on EKC, the relationship between carbon dioxide emissions and economic growth is a monotonically increasing curve. However, in the absence of the informal economy, this empirical result do not support the EKC inverted U hypothesis for carbon dioxide emissions in Nigeria, based on no turning point since the second derivative of the EKC model, based on the coefficients is positive. Fewer years are reflective of higher energy efficiency with minimal contribution in energy consumption reduction from structural changes in GDP at sectoral level. However, overall contribution of aggregate activity effect to reduction in energy consumption is comparatively small resulting from limited number of distributed exports. Factors such as changes in the composition of output, the introduction of cleaner production technology, environmental policies and environmental awareness play significant role in making the decoupling between economic growth and environmental degradation, and will help establish the nexus needed for EKC in Nigeria.

1.0 INTRODUCTION

Nigeria and the economies of the world are heavily reliant on energy since it has become an indispensable force driving all economic activities (Alam, 2006). Energy is considered to be the life line of an economy, the most vital instrument of socio economic development and recognized as one of the most important strategic commodities (Sahir and Qureshi, 2007). Energy is not only essential for the economy but its supply is uncertain (Zaleski, 2001). It is a strategic source that influences the outcomes of wars; fuels and strangles economic development and pollutes as well as cleans up the environment. In the era of globalization, a rapidly increasing demand for energy and dependency of countries on energy indicates that energy will be one of the biggest problems in the world in the next century. Greater energy consumption leads to more economic activity in the nation and as a result a greater economy emerges. In recent times, Nigeria is seen as one of the greatest developing nations in Africa with highly endowed natural resources including potential energy resources. However, increasing access to energy in Nigeria has proved to be not only a continuous challenge but also a pressing issue. Economic growth is a necessary for the nation to proceed from a developing country to a developed nation. For a developing country like Nigeria, the greater the economic growth, the better its chances to become more developed. Consequently, with adequate utilization of energy potentials to meet the demand, the nation would experience highly improved levels of economic growth.

In the recent past, the subject of connecting relationship between energy consumption and macro-economic variables have been analysed by many researchers (Soytas and Sari, 2003; Lee, 2005; Lise, 2006; Chontanawat, 2008). A number of studies have examined this fundamental relationship between energy consumption and several independent variables such as economic growth, financial development, employment and population (Halicioglu, 2009; Ozturk and Acaravci, 2010). On most occasions, the causal relationship between economic growth and energy consumption is often presented with the concept of economic Kuznets curve. However, a link between the EKC and energy efficiency from decomposition analysis has not been incorporated. In the methodology which follows, the relationship between economic growth and efficiency, as reflected on the magnitude of the nation's gross domestic product, is evaluated using index decomposition analysis. The energy consumption pattern for the nation with respect to the energy carriers would be necessary to present a holistic view of the emissions during the considered years. This will form a platform for the establishment of the theoretical environmental Kuznets curve for Nigeria.

2.0 ENVIRONMENTAL KUZNETS CURVE

The Environmental Kuznets Curve (EKC) hypothesis in its broad setup is stated as follows

(Jaunky, 2011):

$$E = f(\psi_t,\ \psi_t,^2\ Z) \quad 1$$

Where *E* is an environmental indicator, ψ is income and Z is other explanatory variables which may influence environmental degradation. However, the other explanatory variables represented by *Z* are not considered in the scope of this work. The relationship between the economic degradation and the economic growth are only considered with reference to the EKC. With this simplification, equation 1 is reduced to the form below:

$$E = f(\psi_t,\ \psi_t,^2) \quad 2$$

It is customary to present the estimation model in logarithm form as follows (Jaunky, 2011; Akbostanci *et al*., 2009):

$$log_e E_t = \alpha + \beta log_e \psi_t + \gamma (log_e \psi_t)^2 + \varepsilon_t \quad 3$$

As obtained in equation 3, $log_e E_t$ is the emissions, $log_e \psi_t$ and $log_e {\psi_t}^2$ both refer to the logarithm of the gross domestic product in unit and dual degrees respectively, *t* is the time, while ε_t is the standard error term needed to be minimised so as to obtain the coefficients. Values of the coefficients are indicative of different functional forms.

$\beta = \gamma = 0$ indicates a level relationship, $\beta < 0, \text{and } \gamma = 0$ indicates a monotonically decreasing linear relationship, $\beta > 0, \text{and } \gamma = 0$ indicates a monotonically increasing linear relationship, $\beta < 0, \text{and } \gamma > 0$ represents a U-shaped relationship and $\beta > 0, \text{and } \gamma < 0$ indicates an inverted U-shaped relationship, hence the name environmental Kuznets curve (EKC). The turning point of the EKC regarding the per capita real income (GDP) and the emissions per capita is obtained below by differentiating equation 3 (with the log terms taken absolutely) with respect to $log_e \psi_t$ to obtain the following:

$$\beta + 2\gamma log_e \psi_t = 0 \quad 4$$

Where $log_e \psi_t = \frac{-\beta}{2\gamma}$ 5

Equation 5 represents the turning point of per capita real income. Furthermore, by substituting the value of equation 5 in equation 3 and neglecting the standard error term, the turning points of the emissions per capita is expressed with equation 6 below:

$$log_e E_t = \alpha + \beta \frac{-\beta}{2\gamma} + \gamma \left(\frac{-\beta}{2\gamma}\right)^2 \quad 6$$

Which simplifies to:

$$E_t = exp\left[\alpha + \frac{-\beta^2}{2\gamma} + \frac{\beta^2}{4\gamma}\right] \quad 7$$

The EKC coefficients are obtained by minimising the standard error in equation 3. Consequently, the values for the EKC coefficients are obtained with the matrix solution below:

$$\begin{bmatrix} N & \sum(log_e\psi_t) & \sum((log_e\psi_t)^2) \\ \sum(log_e\psi_t) & \sum(log_e\psi_t)^2 & \sum((log_e\psi_t)^3) \\ \sum((log_e\psi_t)^2) & \sum(log_e\psi_t)^3 & \sum((log_e\psi_t)^4) \end{bmatrix} * \begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} = \begin{bmatrix} \sum(log_e E_t) \\ \sum(log_e\psi_t * log_e E_t) \\ \sum((log_e\psi_t)^2 * log_e E_t) \end{bmatrix} \quad 8$$

3.0 CARBON DIOXIDE EMISSIONS

The empirical model required to calculate the quantity of carbon dioxide emissions from fossil energy is presented by quantifying the contributions of five different factors: scale of the economy, industrial activity mix, sectoral energy intensity, sectoral energy mix, and the values of emission factors. Additionally, different sub-categories are considered, concerning industrial sectors and fuel type. The carbon dioxide emissions can be written as (Robalino *et al*. 2013; 2014):

$$C = \sum_{ij} C_{ij} = Q \sum_{ij} \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = Q \sum_{ij} S_i * I_i * M_{ij} * U_{ij} \quad 9$$

Where ***C*** is the total carbon dioxide emissions for the whole sectors in a given year, C_{ij} is the total carbon dioxide emissions arising from fuel type ***j*** in the ***i****th* sector, ***Q*** is the total GDP of the country, Q_i is the GDP generated by the ***i****th* sector, E_i is the energy consumption in the ***i****th* sector, E_{ij} is the energy due to consumption of fuel ***j*** in the ***i^th^*** sector, S_i is the share of the GDP of the i^{th} sector to the total GDP of the considered sectors, I_i is the energy intensity in the i^{th} sector, M_{ij} is the energy matrix expressed for the i^{th} sector as the energy from fuel type ***j*** to the total energy in the sector and U_{ij} is the carbon dioxide emission factor for the i^{th} sector

Economic data for the nation's economic growth and accompanying carbon dioxide emissions can be found in the Nigeria Bureau of Statistics Bulletin as well as the Central Bank of Nigeria Statistical Bulletin annually. An extract of such a relationship for the years 1980 to 2010 is shown on Table 4.1.

4.0 INDEX DECOMPOSITION BASED SECTORAL ENERGY EFFICIENCY

The microeconomics of end-use energy saving can be assessed using the concept of energy efficiency and frugality. In this context, the energy efficiency refer to the technical ratio between energy input and output services that can be modified with technical improvements (Oikonomou et al., 2009). The energy efficiency is defined as:

$$\boldsymbol{EF = \frac{E_t}{Q_t} = I_t} \qquad 10$$

$$\boldsymbol{EF = \sum_i \frac{E_i{}^T}{Q_i{}^T}\frac{Q_i{}^T}{Q^T}} \qquad 11$$

$$EF = \sum_i \left(\frac{E_i{}^T - E_i{}^0}{ln[E_i{}^T] - ln[E_i{}^0]}\right) ln\left(\left[\frac{I_i{}^T}{I_i{}^0}\right]\left[\frac{Q_i{}^T}{Q_i{}^0}\right]\right) \qquad 12$$

Expanding Eqn. 12, the following is obtained:

$$\boldsymbol{EF = I_\Delta + S_\Delta} \qquad 13$$

Where $\boldsymbol{I_\Delta}$ and $\boldsymbol{S_\Delta}$refer to the changes in energy consumption with respect to intensity and economic structure. Changes due to GDP growth rate is also synonymous with the terms of Equ. 12. The energy efficiency is calculated sectorally using the expression shown in equation 12, where the GDP and energy intensity have been replaced by ***Q*** and ***I*** respectively.

5.0 RESULTS AND DISCUSSION

The results from the economic Kuznets curve, the emissions from the energy consumption, and the analysis for determination of the EKC hypothesis for Nigeria are presented. The general organisation for the results is organised as follows: first is the analysis of the energy consumption data into suitable data structures to accommodate detailed emissions determination, second is the computation of the emissions from the consumption for the considered years, third is the determination of the EKC constants by employing the method of least squares, and fourth is the presentation of energy efficiency variation. Based on Table 1, the structured data is presented below:

Table 1: Structured data of Nigeria's aggregate energy consumption by fuel type

Year	**Aggregate Consumption [toe]**	**As percentage of total energy consumption**			
		Consumption from Crude oil [toe]	Consumption from Natural gas [toe]	Consumption from Coal [toe]	Hydro/Wind/ Solar [toe]
1980	10600000	8448200	943400	169600	1028200
1982	13000000	10686000	1248000	65000	1001000
1984	14000000	10458000	2422000	70000	1050000
1986	14800000	10389600	2900800	118400	1406000
1988	16700000	11656600	3323300	83500	1653300
1990	17600000	12548800	3273600	70400	1724800
1992	19800000	13186800	4316400	99000	2197800
1994	18700000	12529000	4020500	37400	2113100
1996	21400000	14252400	4836400	21400	2311200
1998	20600000	12978000	5211800	20600	2389600

2000	20400000	12240000	5956800	81600	2121600
2002	23300000	14981900	5545400	46600	2749400
2004	24800000	13788800	8233600	N/A	2777600
2006	26500000	14151000	9646000	79500	2623500
2008	25200000	14238000	9853200	100800	1033200
2010	23900000	13766400	7337300	23900	2820200

Source: CBN (2011); NBS, (2011)

Data for the computation has been taken from the summation of energy consumption and corresponding gross domestic product for the years and stated in the Table 2:

Table 2: Aggregate energy consumption and corresponding GDP at real current prices

Year	Aggregate Consumption [toe]	Gross Domestic Product GDP [Million Naira]
1980	10600000	31546.8
1982	13000000	199685.3
1984	14000000	183563.0
1986	14800000	205971.4
1988	16700000	219875.6
1990	17600000	267550.0
1992	19800000	271365.5
1994	18700000	275450.6
1996	21400000	293745.4
1998	20600000	310890.1
2000	20400000	329178.7
2002	23300000	433203.5
2004	24800000	527576.0
2006	26500000	595821.6
2008	25200000	634251.1
2010	23900000	674889.0

Table 3: Carbon dioxide emissions for the fuels over the years

Year	Carbon Dioxide Emissions [tCO_2]			
	Natural Gas	Crude Oil	Coal	Total
1980	2492460	25928126	671769	29092355
1982	3297212	32796093	257459	36350764
1984	6398917	32096345	277263	38772524
1986	7663905	31886420	468971	40019296
1988	8780149	35774933	330735	44885817
1990	8648841	38513158	278848	47440847
1992	11403916	40471225	392129	52267271
1994	10622149	38452391	148138	49222677
1996	12777754	43741628	84763	56604145
1998	13769560	39830403	81595	53681558
2000	15737848	37565429	323210	53626486
2002	14650930	45980515	184578	60816023
2004	21753147	42318806	N/A	64071953
2006	25484703	43430424	314892	69230018
2008	26032125	43697433	399259	70128817
2010	19385125	42250059	94666	61729849

The results from the EKC hypothesis is presented using the data on economic growth and the energy consumption. Normally, an avalanche of data for a good number of years is needed for this category of analysis. In Table 1, the energy sources and their corresponding utilisation over the years was highlighted. This data was necessary, though not completely sufficient on the sectoral energy mix, to make deduction on the emissions which stems from its utilisation. At any rate, an aggregate of the overall energy consumption is shown on that Table. A steady increase was observed as the years passed, reflecting corresponding increase in the population- a factor that completely affect energy consumption. The pattern of consumption reflects the times, and the available mechanisms for energy conversion processes. In Table 1, a structured tabular representation was made to express the energy quota of the carriers. A clearer picture of the relative contribution of crude oil (which occupies a higher percentage), natural gas (occupying the second largest contribution), then hydro mixed with the minimal generation from renewable energy sources, and the comparatively small contribution from coal is shown in Fig. 1.

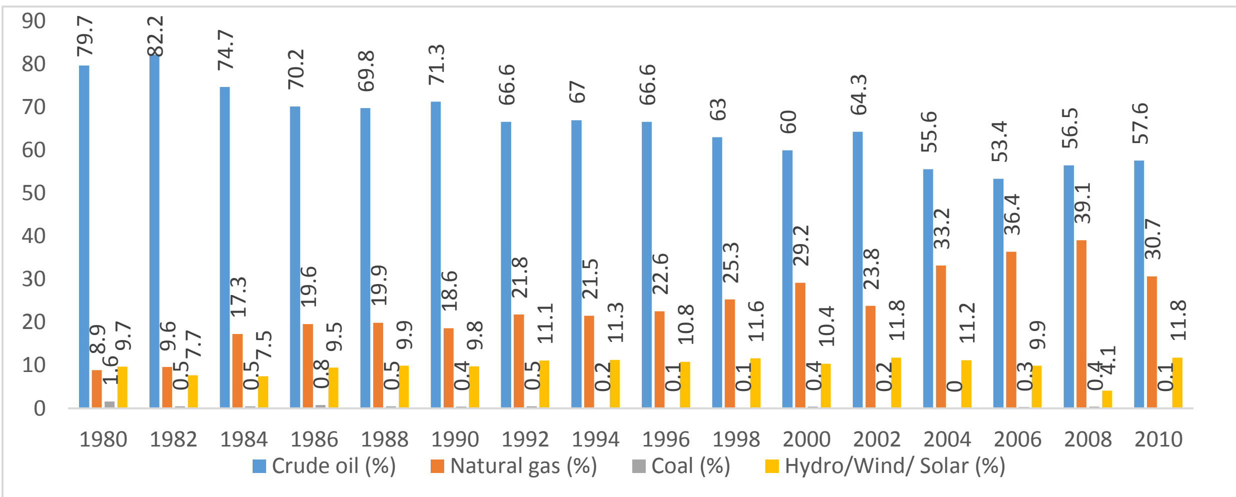

Figure 1: Energy consumption with different energy carriers

6. ECONOMIC GROWTH

The economic growth data is presented for the whole country which is a function of the whole active and subsectors. However, for the purpose of this research, emphasis has been paid to the aggregate values which are presented for the years 1980 through 2010 in Fig. 2.

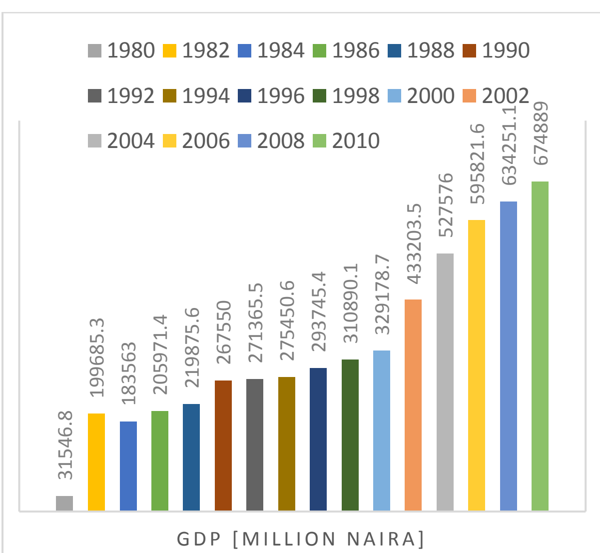

Figure 2 Structure of Nigeria's economic growth between 1980 and 2010

The trend of the economic growth values is in even years to reflect the data for energy consumption. The economic growth has reflected a steady rise, typical of the developing Nigerian economy. This steady increase is comparatively slow between 1980 and 1999 when the country was headed in different military regimes. Although there was annual economic growth as reflected between 1980 and 1999 in Fig. 2, the increase fluctuates between 5.515%. However, with a shift to the current democratic dispensation, the economic growth values have risen realistically to 24.01%, 17.89%, and 11.45% for 2002, 2004, and 2006 respectively. This surge in economic growth is studied in the light of the continued burning of fossil fuels.

7. CARBON DIOXIDE EMISSIONS

The mass of carbon dioxide emissions over the years is presented in Table 3 where the relative contribution of the energy carriers is clearly shown. The emissions are seen to increase linearly with the volume of energy consumption. This linear relationship is constant for a specific fuel type depending on the emission coefficient as shown in Table 3. The emission coefficient for the fourth energy source in Table 3 i.e. hydro/solar/wind is zero thus contributing to a great reduction in emissions over the years as generation from hydro, and solar sources increase. Corresponding to the increase in economic growth over the years, there is a similar increase in the emissions in consonance with the environmental curve hypothesis. In Fig. 3, a plot of the emissions for the energy carriers is shown to visualise their relative contribution over the years. The shape of the emissions on the chart suggests an adherence to the environmental Kuznets curve hypothesis.

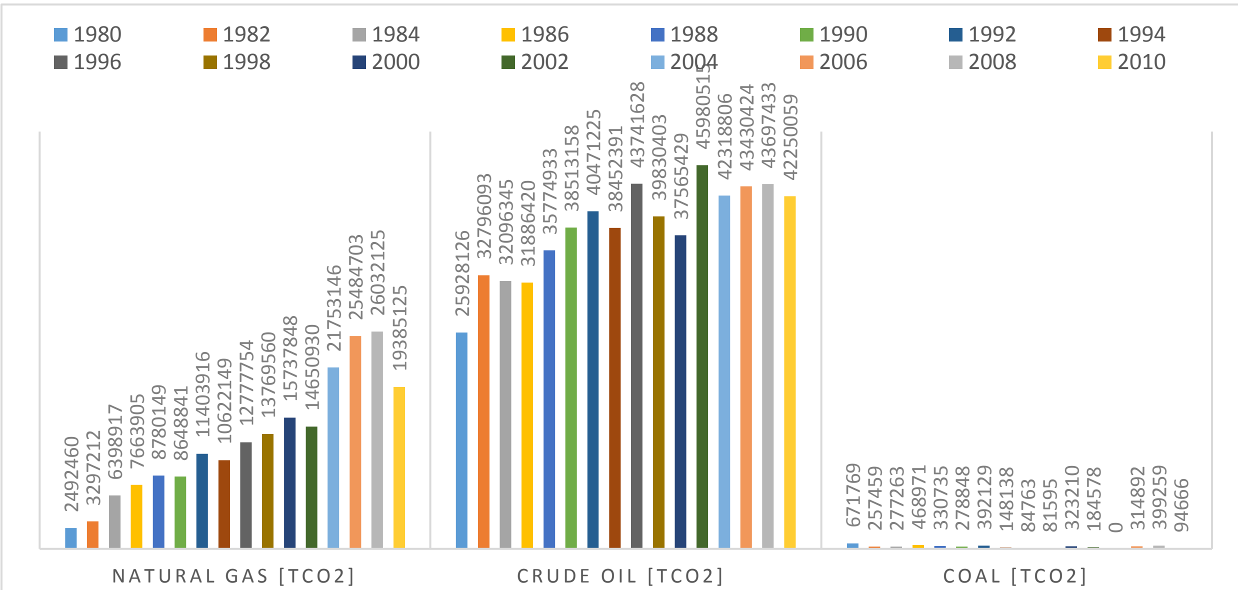

Figure 3: Yearly Emissions from Fossil Fuels

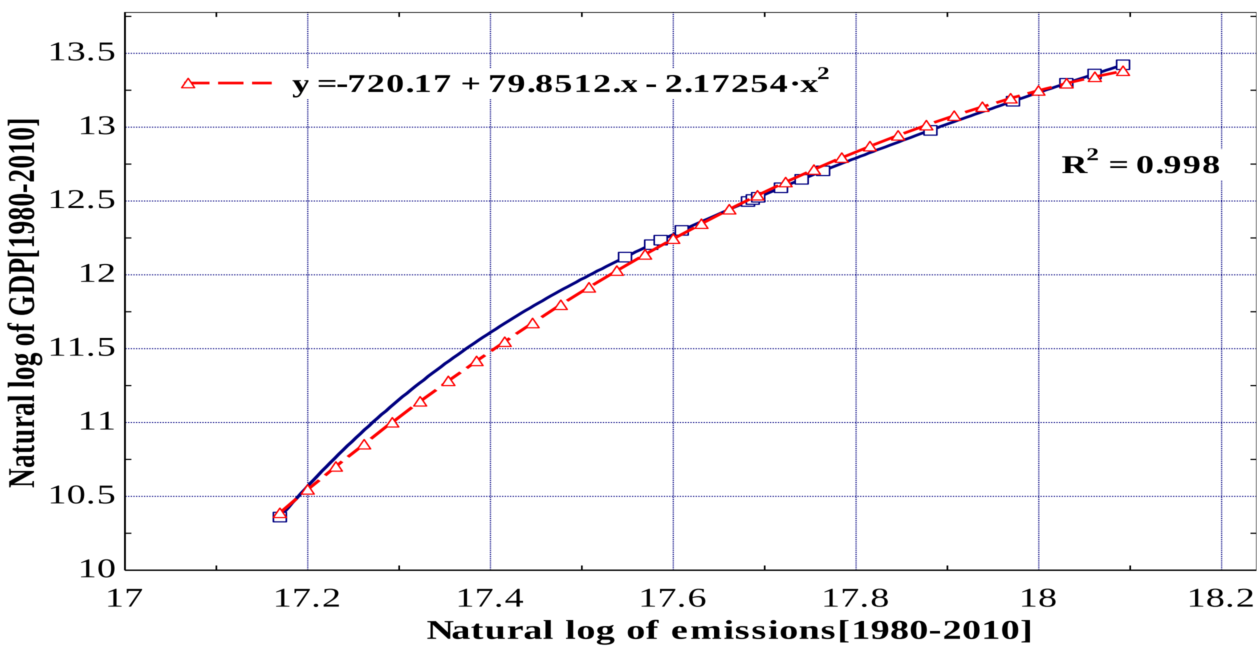

Figure 4: The EKC for Nigeria between 1980 and 2010

From the model obtained with the available data on EKC, the relationship between carbon dioxide emissions and economic growth is a monotonically increasing curve. Consequently, in the absence of the informal economy, our empirical results do not support the EKC inverted U hypothesis for carbon dioxide emissions Nigeria. This relationship is shown on Fig. 4, where for the present model, the relationship between the emissions and the economic growth presently possess no turning point since the second derivative of Eqn. 3 based on the coefficients is positive.

Table 4: Index decomposition of energy consumption and efficiency

Year	Changes due to Structure (toe)	Changes due to Intensity (toe)	Changes due to Activity (toe)
1991	123336.4	2251777.556	-1125115.49
1992	1847918	2250690.667	552132.4026
1993	-2750311	-1093138.848	-820602.645
1994	-2106414	-1138718.505	5329320.671
1995	6042076	-2471159.053	33753600.12
1996	1383673	-4940773.493	25564001.51
1997	-4026088	-2994107.729	1595892.601
1998	-8204210	-3160934.117	-6651257.85
1999	3126729	-938190.7578	-44252358
2000	3843916	-791368.3734	7324728.334
2001	-3757673	826484.5585	-2752558.02
2002	-6901386	729799.691	8418049.462
2003	4130458	2137853.042	6614656.723
2004	6037787	2318220.719	6940943.678
2005	552627.3	-5904233.881	14338118.4
2006	-643656	-7618301.574	15008492.39
2007	-1338763	-4072666.37	8559055.879
2008	-603207	-4789028.395	18048544.86
2009	-6175288	-16917246.6	-15862820.94
2010	6668282	-18002018.12	18212505.18

Index decomposition of energy consumption for the years is presented to determine energy efficiency improvement and contribution to reduction in consumption. Changes in activity, structure and intensity effects are shown using the index decomposition methods in Table 4. Computations have been made for the sectors with the results presented accordingly. Energy efficiency improvement contribution is shown with the effect of energy intensity as negative while the activity effect, which characterizes reduction in energy consumption is observed for a couple of years. Comparatively, energy efficiencies were recorded due to structure, intensity, and activity. For instance, higher level of economic activity resulted in energy savings and efficiency in 1993 and 1994 due to intensity and energy structure. An all-round energy savings was recorded in 1993 when decomposition results were spread among the effects. Similar effect is observed for decomposition results in 2009. The years 1993 through 2000 are reflective of higher energy efficiency with minimal contribution in energy consumption reduction from structural changes in GDP at sectoral level. However, overall contribution of aggregate activity effect to reduction in energy consumption is comparatively small resulting from limited number of exports. This trend is not remedied properly and can be tackled through development of local content to improve aggregate activity effect in energy efficiency.

8. CONCLUSION AND RECOMMENDATIONS

A study on the relationship between economic growth and carbon emissions using the environmental Kuznets curve was performed for Nigeria using historical data on energy consumption and economic growth. In line with the logarithm of the emissions and economic growth, and the standard EKC hypothesis, a monotonically increasing relationship was observed. However, despite the above findings, it is noteworthy to recall that this result does not provide much information about the reasons behind the observed monotonically increasing relationship between environmental degradation and income. Factors such as changes in the composition of output, the introduction of cleaner production technology, environmental policies and environmental awareness play significant role in making more detailed relationship between economic growth and environmental. This study recommends an integrated approach which will account for other potential determinants of carbon dioxide emissions such as sectoral energy consumption, foreign trade, urbanization, capital investment and employment to the EKC model.

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