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ECONOMIC GROWTH AND EMISSIONS: TESTING THE ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS FOR ECOWAS COUNTRIES.

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1. Executive Summary

The study examines the relationship between environmental degradation and per capita income using two variants of emissions-sulfur dioxide and carbon dioxide in ECOWAS countries. The specific objective is to establish whether the estimated relationships corroborate the inverted U-shape hypothesis as exemplified by the Environmental Kuznets curves (EKCs). Using panel fixed and random effects estimation techniques, the study indicates the existence of EKCs for the two indicators of environmental quality- $SO_2$and CO_2.

This result is in tandem with the EKC Hypothesis. Experimentation with augmented quadratic equations, however, does not in some cases produce consistent results forSO_2; while cubic polynomial forms suggest N-shaped EKCs for CO_2. The turning points estimated for the different indicators of environmental quality are relatively low, thus suggesting a demonstration of the low level of development in the sub-region occasioned by high incidence of poverty. The major drivers of SO_2 in the region are fuel processing and fuel combustion led by Nigeria. For CO_2 emissions, it is driven by rapid population growth that is equally induced by Nigeria. The polity variable which interacted significantly with the income variable to create the inverted-U shape EKC signals the importance of public institutions on environmental quality.

Although ECOWAS countries may have benefited from early learning effect sand environmental awareness, the implication is that policy makers must be proactive to sustain the current trend as the region enters the phase of industrialization and may not need to wait for too long to improve environmental conditions as is the case with developed countries. One of such ways is through the use of environmental tax instruments such as fuel tax which has been advised to be progressive for some African countries. By way of recommendation, a functional population policy should be implemented particularly in Nigeria.

2. Introduction

History of the economic discourse on the environment-growth relationship which underpins the Environmental Kuznets Curve (EKC)dates back to the 1970s when some scientists began to question the compatibility of natural resource availability with sustained economic growth (Meadows, Meadows, Zahn, and Milling, 1972). The other strand of the divide championed by neoclassical economists such as Beckerman (1974) and Jahoda (1973) among others; opposed the limits to growth aphorism due to resource constraints as a problem. More importantly, as the perception of general interdependence between ecosystems and economies gains traction, economists broaden their view on the links between them.

A comprehensible hypothesis about the relationship between environmental quality and economic growth was first alluded to by Grossman and Krueger (1991); in their remarks they posit that during the early stages of economic development, a country experiences increased environmental degradation which will increase until a certain level of income is reached (known as the turning point). At that level, environmental improvement will occur. What is implied in this analysis is that when agriculture and allied activities as well as light manufacturing dominate the typical economy (early stage of economic development), pollution intensity will be generally low. However, as the economy moves into heavy industry, pollution will tend to increase. Besides, as the economy shifts into high technology and services, pollution intensity will tend to decline. According to Grossman and Krueger, this produces an inverted U-shaped curve, analogous to that proposed by Kuznets (1955) in the relationship that exists between income inequality and average national income. Kuznets hypothesizes that economic inequality increases over time and then after a threshold becomes more equal as per capita income increases; hence the income-environment nexus is dubbed the “environmental Kuznets curve” (EKC).

Since the seminal works of Grossman and Krueger’s (1991) particularly on the potential environmental impacts of NAFTA, and the 1992 World Bank Report, interest in studies on the environment-income relationship has been aroused. Many studies on the subject have come on stream in efforts to estimate, interpret and understand the existence and shape of the EKCs with respect to various emissions and greenhouse gases. In the light of those studies that followed the thought provoking Grossman and Krueger's findings, EKCs are now known to have different shapes depending on the distinctive measurement of environmental degradation and datasets employed (see Cole and Neumayer, 2005; Stern, 2004; Yandle, Bhattarai and Vijayaraghavan, 2004 for overviews). In all and as can easily be anticipated, the statistical and econometric evidence of the EKC relationship is mixed and its interpretation ambiguous. Consequently, little may be done in breaking new ground in attempt to synthesize the evidence and assess where matters stand. However, the contribution of this paper to the EKC- SO_2 and CO_2empirical literature, to the author's mind, is novel in its application to the ECOWAS sub-region.

Second, in their quest for economic integration and diversification, ECOWAS economies move into the next stage of economic growth with probable increase in per capita income, mitigating environmental degradation in the sub-region through appropriate policy design becomes inevitable.

Third, the reality of rapid population growth (Nigeria is Africa's most populous country) coupled with increased urbanization in the sub-region are matters of concern as both can, on the one hand, contribute to over-exploitation of the ecosystems through complex feedbacks that have important implications for sustainable resource use, and on the other hand, further deteriorate the relationship between their levels of economic growth and emission of pollutants (Apergis and Ozturk, 2015; Cumming, Buerkert,Hoffmann,Schlecht,von Cramon-Taubadel and Tscharntke, 2014; Jiang, Lin and Zhuang, 2008).

Fourth, Nigeria (Africa's biggest oil producer and 13th largest producer of oil in the world with daily production reaching about 2.4 million barrels) is the only member of the Organization of Oil Exporting Countries (OPEC) in ECOWAS and accounts for over 76% of the sub-region's GDP. Its enjoyment of relatively cheaper price of fossil fuels, reflecting government resource subsidies, implies that the sub-region could experience relatively higher rates of atmospheric fossil fuel and irreversible environmental damage. The prognosis however, is a matter of empiricism which this study seeks to address. Nigeria alone is ranked among the top 50 CO_2 emitter countries in the world and this attracts attention.

The significance of testing for the existence of an EKC therefore stems from the fact that, it is far from a mere academic exercise. If an EKC is indeed a generalized phenomenon, this will be an indication, *ceteris paribus*, that environmental degradation will automatically fall in the long run as incomes rise. Nevertheless, if the EKC proposition does not hold, this would be an indication that policy intervention would be necessary to curb pollution and make sustainable development a reality. A large deviation would be an indication that policy action is still required to reduce current pollution intensities even as income rises. The modifying effects would therefore provide the framework for a holistic approach to environmental policy design (Orubu and Omotor, 2011).

The dawn of the EKC has so far raised some questions: do all aspects of environmental quality deteriorate or improve systematically with economic development? Can the pattern of growth versus environmental impact as established by the developed countries EKCs be replicated for developing countries path? For how long will developing countries have to wait before tunneling the EKC? Is the policy implication for poor countries that they should grow themselves out of environmental problems rather than implementing stricter regulation now?

Although the study addresses some of the questions raised about the EKCs, it nonetheless acknowledges that there have been scores of empirical EKC publications since Grossman and Krueger's path-breaking work. The major focus of the study, however, is to estimate EKCs for ECOWAS countries using two specific measures of environmental indicators: sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions. The choice of these indicators of environmental degradation is based on the fact that, although a number of studies of the EKC with respect to developing countries exist for some pollutants, detailed studies that deal specifically with ECOWAS countries using sulfur dioxide emission are few and far between. Second, the existence of a relatively consistent country level data series for the ECOWAS countries selected for the study, also informed the choice. The specific objectives of this study are thus to:

- estimate the EKCs model based on the emissions and determine a threshold income level for ECOWAS countries; and
- ascertain the effect of other control variables such as population density and policy influences on the quality of the environment.

2.1 Scope of the Study

The scope of this study is limited to the analysis of the relationship between environmental emissions and per capita income as espoused in the environmental Kuznets Curve hypothesis. The EKCs would precisely be estimated for two indicators of air quality (AQI), drawing on panel data for selected ECOWAS countries. These environmental emissions (AQI) are sulfur dioxide (SO_2) and carbon dioxide (CO_2).

The effects of policy variables such as population density, quality of institutions, population growth and trade openness on the selected AQI are also explored. The expectation is that such policy variables which could lower pollution concentration if adequately captured in the analyses should strengthen the policy implications of the study. The analysis is limited in scope to time series of the ECOWAS countries for which relevant data is steadily available.

3. Review of Related Literature

The basic hypothesis of the environmental Kuznets curve is that, there exists an inverted "U"-shape relationship between economic growth and environmental degradation. The explanation is that in the early stages of economic growth, environmental quality improves until it reaches the peak, afterwards it declines when the income per capita increases. Subsequently, economic development would eventually lead to environmental improvement (de Groot, Linders, Rietveld and Subramanian, 2004).

Series of studies have developed theoretical models on how preferences and technology interact to result in different time paths of environmental quality (Selden and Song, 1995; Andreoni and Levinson, 2001) among others. This, notwithstanding, the EKC though an essentially empirical phenomenon, is in much of the literature provocative (Stern, 2003) and their results inconclusive.

Studies that confirm the EKC hypothesis for different pollutants are Shafik and Bandyopadhyay (1992) and Aldy (2005). In the literature, studies have questioned the real existence of an inverse-U-shaped curve by empirical evidence. Khanna's (2002) result is a U-shaped relationship instead of the inverted-U-shaped EKC. Akbostanci, Turut-Asik and Tunc (2009) find an N-shaped curve for CO_2 and; PM_{10} and SO_2, respectively. Lekakis (2000), however, finds no relation between economic growth and environmental degradation.

The techniques of analyzing the EKC relationship over time have also varied, so also are the various forms of dataset ranging from time series, cross-sectional, cross-country to panel or longitudinal analyses with a set of control variables widely used in the empirical literature. Examples of such control variables are literacy rate (Orubu and Omotor, 2011); trade and structural change (Suri and Chapman, 1998), technology and technological progress (Baiardi, 2012), corruption (Leitao, 2010), among others.

At some other instances, studies (though not directly on determining the existence of an EKC) on designing economic instruments for environmental regulation are underway. Examples of such studies are Orubu (2004), Ziramba, Kumo and Akinboade (2009), among others. For instance, West (2004) suggests that environmental taxes particularly gasoline tax are mildly regressive and hence not popular option in policy design. Ziramba, et.al, conclusion in the case of the South Africa is that fuel expenditures are progressive and that fuel tax would be an effective and desirable instrument for pollution control.

Other than OECD countries, some recent studies have concentrated on Africa and Asia regions. Examples are Osabuohien, Efobi and Gitau (2014) and Apergis and Ozturkb (2015). For sake of emphasis, Osabuohien, Efobi and Gitau (2014) study aim to establish the applicability of the EKC hypothesis in 50 African countries, using data from 1995–2010. The extension made includes the use of panel cointegration to address some of the econometric concerns. The empirical results suggest the existence of a long-term relationship between CO_2 and particulate matter emissions jointly with per capita income and other variables, including institutional factors and trade. The study recommends the need for African countries to reduce the level of environmental pollution at higher levels of economic development. Apergis and Ozturkb (2015) focusing on income and policies, investigate the existence of the EKC hypothesis for 14 Asian countries spanning the period 1990– 2011. The study employed the Generalized Method Moments (GMM) on panel dataset to test the EKC hypothesis. The multivariate framework includes CO_2 emissions, GDP per capita, population density, land, industry shares in GDP, and four indicators that measure the quality of institutions. The estimates have the expected signs and are statistically significant; yielding empirical support to the presence of an EKC hypothesis. The study proposes measures to edit regulations related with reducing the greenhouse gas rising from industry, transport and heating. Other suggested measures according to the study are implementing carbon sequestration technologies in power plants and supporting green investments through the application of environmental technologies. Table A1 in Appendix 1 presents a chronological summary of EKC studies for both developed and developing countries.

4. Environmental Issues in ECOWAS: Stylized Facts

As noted earlier, the two emissions used in this study are Sulfur Dioxide (SO_2) and Carbon Dioxide (CO_2). SO_2 is emitted when fuels containing sulfur are combusted. In the air, it can form tiny particles called aerosols, creating new ones or building up old ones. Aerosol particles help form cloud drops and potentially changes amount of rainfall. Both clouds and the aerosols themselves reflect sunlight and reduce the amount of energy absorbed by the planet (Smith, et.al; 2011). Sulfur dioxide has the potential to acidify rain, soil and lakes, and it can counteract some of the warming effect of carbon dioxide. The subsequent impacts of acid deposition can be significant, including adverse effects on aquatic ecosystems in rivers and lakes and damage to forests, crops and other vegetation (EEA, 2011).These concerns no doubt are worrisome and have aided the shift in the frontier of environment-development treatise.

The environment-development paradigm which shifted to sustainable development began in the 1970s with the aim of formulating sustainable development policies that will curtail emissions in the development process. The dialogues which followed the discourse were to conserve the deteriorating environment and these resulted in a series of government commitments covering at least nine treaties. Chief among those action plans are the Convention on Biological Diversity (Earth Summit in 1992), United Nations Framework Convention on Climate Change also known as the Kyoto Protocol (1997), United Nations Convention to Combat Desertification (1994, 1996) and the most recent in these group; the Stockholm Convention which is an international legally binding instrument to protect human health and the environment from persistent organic pollutants. The Stockholm Convention was adopted in 2001 but put into force in 2004 (World Development Indicators, 2010:211).

Multilateral Environmental Agreements and Modifications are well up to 1,257(Mitchell, 2015). Among these are 540 Agreements and 222 Protocols. These numbers are still counting; however, as observed in the World Development Indicators (2010: 211), signing of these treaties does not always guarantee that governments will comply with treaty obligations. This notwithstanding a fundamental question is how the ECOWAS sub-region has fared relatively in some of these environmental agreements and profile in the midst of industrialized nations?

Although all ECOWAS countries have participated in signing most of the treaties since the 1990s, the United States of America for instance, did not sign some of the international treaties and agreements launched in the wake of the 1972 United Nations Conference on Human Environment in Stockholm and the 1992 United Nations Conference on Environment and Development (Earth Summit) in Rio de Janeiro. It was only recently in 2012 surprisingly the United States became the first major industrialized nation in the world to meet the United Nation's original Kyoto Protocol 2012 with target for CO_2 reductions without ever ratifying it (Watts, 2013). It became international law when Russia ratified it in November 2004. The United States never ratified Kyoto Protocol even though then Vice President Al Gore of the US signed it. A second observation is that Germany and Japan are probably yet to prepare national environmental profiles and biodiversity strategies and profiles. It is also worthy of note that there exist an ECOWAS Environmental Policy (2008) which signals commitment and appreciation of the consequences of environmental problems by political leaders of the region.

4.1. Profile of SO_2 emissions in ECOWAS countries

The main sources of SO_2 emissions in the ECOWAS region as reported in Figure 2 are fuel processing (wholly contributed by Nigeria) which accounts for 78 per cent of total anthropogenic SO_2 and petroleum combustion 18 per cent. While coal combustion contributed a paltry 1 per cent of the total share of sulfur emissions; Nigeria's accounted for the total coal combustion during the period under review; but now drastically declined probably reflecting increased demand forpetroleum combustion. In essence, fuel processing is the major driver of sulfur dioxide composition in the region and solely contributed by Nigeria, which can be related to the growth in activities of the oil industry.

A comparative examination of the data (Smith, et.al, 2011) shows that SO_2 emission in ECOWAS countries ranked relatively lower than what obtained in some industrial countries; though not surprising. For example, the mean or average SO_2 concentration for the period, 1960-2005 for Benin, Cote d'Ivoire, Ghana, Nigeria, Senegal and Togo stood at 2.5, 20.1, 18.8, 361.7, 20.5 and 202 Gg, respectively; while those of China, Germany, Japan, UK and USA, stood at 14224.6, 5597.1, 2057.6, 4070.7 and 22147.7, respectively (Smith, et.al, 2011). A fundamental lesson to be deduced from Figure3when SO_2 concentrations for the selected ECOWAS countries are compared with the selected Industrial nations is that, ECOWAS countries may have the benefit of learning early and by involving in environmental activism and awareness maynot need to wait for too long for per capita income to improve to the levels recorded in industrial nations before they begin to appreciate cleaner environment. In other words, the challenge developing countries including those in the ECOWAS region face is how to improve the EKC for instance by pressing it downward, or by reaching the turning point faster, in their future development (Kander, 2002).

4.2. Profile of CO_2emissions in ECOWAS countries

It has been argued that, given the current level of economic development in the ECOWAS region, recorded carbon per capita may be rising in recent years. This fear is buttressed by the fact that as the region's economy grows; carbon dioxide per capita may escalate as a result of industrialization. In 1960 the rate of increase per year was 0.71 PPM (parts per million) while the rate of increase was 2.14 PPM per year in 2005 (Ernst-Georg, 2010). Comparatively, average measures of CO_2 per capita for ECOWAS countries are relatively low, compared to the numbers recorded for industrial countries. For example, CO_2 for China, Japan, UK and USA stood at 2.23, 8.41, 10.08 and 19.81 respectively in 1965-2009 (World Bank, 2013). These figures may be compared with those of Benin, Burkina Faso, Cote d'Ivoire, Gambia The, Ghana, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo measured at 0.19, 0.06, 0.48, 0.19, 0.29, 0.46, 0.05, 0.09, 0.60, 0.42, 0.33 and 0.21, respectively (World Bank, 2013).

The ECOWAS carbon dioxide emission intensity per capita averages are equally less than the SSA average and seem to be declining as portrayed in Figure 4. This notwithstanding, recent attitudinal change and concernin the climate change challengesparticularly by China and the United States who hitherto were adamant in reduction of their emissions of CO_2, further provide the impetus for curbing CO_2 emissions by developing countries. This interest is informedby the fact that the ECOWAS region is in quest for rapid industrialization and carbon per capita may increase as the region industrializes. African countries may therefore, do better, by deliberately coming up with measures to curb the trend towards increased carbon intensity. An unanswered question that comes to bear is what the complex drivers of CO_2 emissions in the ECOWAS region are even at its present level of development?

In applying an accounting methodology based on a log mean Divisia Index, Kojima and Bacon (2009) in their analysis decompose countries' absolute levels of CO_2 emissions from the combustion of fossil fuels as well as the levels of emissions per capita and per unit of gross domestic product (GDP). The six ECOWAS countries' (with consistent dataset) performance ranges closely (probably given that they relatively belong to the same income group) depending on metric used as reported in Table 1.

The methodology provides for changes in emissions which are separated into five factors:

- C_{eff} = carbon intensity of fossil fuels consumed;
- S_{eff} = share of fossil fuels in total energy used (fossil fuel intensity of energy);
- I_{eff} = energy required to produce a unit of GDP (energy intensity);
- G_{eff} = GDP per capita; and
- P_{eff} = Population

Some inferences can be made from the decomposition of the selected ECOWAS countries emissions illustrated in Table 1 and Figure 6 during the period 1994-1996 to 2000-2004. First, the net increase in CO_2 emissions for the ECOWAS countries over the period is 30.98 million metric tonnes. Second, the rapid growth of population and GDP per capita contributed most of the net increase in CO_2 emissions in the region. This was closely followed by fossil fuel intensity of energy. Third, carbon intensity of fossil fuels and fossil fuel intensity of energy increased CO_2 by 6.65 million metric tonne and 8.5 million metric tonnes, respectively. Fourth, offsetting theseincreases was a marked reduction in energy intensity of total energy which reduced total CO_2emissions in the selected ECOWAS countries by 8.25 million tonnes (equally a sign of economic underdevelopment). Fifth and very strongly, Nigeria alone is the major emitter of CO_2 emissions in the region based on the selected ECOWAS countries figures and accounted for almost 64 per cent of the emissions during the period with a 0.00 conversion efficiency (V_{eff}) level.Sixth, as energy intensity in the ECOWAS countries is falling,fossil fuel intensity in contrast increased (probably due to declining traditional use of biomass that require hours of manual collection). On a separate note, Spence (2009) argues that a bracket of low income countries in which the ECOWAS countries belong, be permitted to increase their emissions into the foreseeable future. In contrast, it is the view of this paper that this set of countries should rather be encouraged to mitigate the factors that contribute to rising emissions by their own planning and policy efforts. This can be achieved through energy conservation, energy efficiency improvement via low-carbon energy sources, strengthening institutions, structural changes in their economies and population control especially in the case of Nigeria.

5. Theoretical Framework and Model Specification

Although many environmental economists take the EKC as a stylised fact that needs to be explained by theory despite the pieces of evidence that it may not apply to all pollutants or environmental impacts (Stern, 2004), some substantial efforts have been made to provide a theoretical framework that rationalizes the subsistence of the EKC as an observable fact. The rest of this section which draws heavily on Orubu, et.al. (2009), offers an interesting micro-structure from Levinson (2000). The Levinson micro model which is derived from a polynomial pollution-income curve is based on the utility maximizing behaviour of economic agents in which pollution rises at lower levels of income, but falls at higher levels. In the modified Levinson's Model, the EKC explanation can be presented in five basic equations (a social utility function, a pollution function, a modified pollution function, an abatement function, and a constraint, respectively);

$$U = U(C,P),\ P = P(C,F),\ P = C - C^{\alpha}F^{\beta},\ A = C^{\alpha}F^{\beta},\ C + F = Y \qquad (1)$$

Where U = total utility, C = consumption, P = Pollution effect of the processes of production and consumption in the economy, F = effort expended in abating pollution, A = total abatement, Y = income, while α and β are parameters. From these equations, the consumption-income, and pollution-income equations are derived as in Equation 2:

$$\frac{\partial P}{\partial Y} = \frac{\alpha}{\alpha+\beta} - (\alpha+\beta)\left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta} Y^{(\alpha+\beta-1)} \qquad (2)$$

The sign of which depends on the parameters α and β.

From Equation (2), note that if $(\alpha+\beta) > 1$, abatement will reflect increasing returns to scale, and the pollution curve will correspond to the EKC in Figure 6(b). If $(\alpha+\beta) < 1$, then abatement exhibits diminishing returns to scale; EKC is convex and when, $(\alpha+\beta) = 1$, effort spent abating pollution has constant returns to scale, and income-pollution is constant, as in Figure 6a.

5.1 Model Specification

With the foregoing, and given the framework already considered above, the basic foundation of the EKC formulation is that pollution intensity worsens as income levels rise, but eventually falls once income crosses some threshold. By this postulation, the prime quadratic EKC equation in logarithms can be specified as:

$$In(e)_t = \alpha_1 + \beta_1 In(y)_t + \beta_2 In(y)^2 + \mu_t \qquad (3)$$

where e = indicator of environmental degradation or indicator

y = GDP per capita at constant prices (US$2000) or inform of concentrations

t = time

In= natural logarithm of the relevant variable

μ = stochastic disturbance term with zero mean and finite variance

For the EKC hypothesis to be established, $\beta_1 > 0; \beta_2 < 0$, and both must be statistically significant. In a longitudinal data analysis, a parametric specification of Equation (3) would be formulated as:

$$In(e_{it}) = \alpha_i + \gamma_{it} + \beta_1 In(y_{it}) + \beta_2 (In(y_{it}))^2 + \mu_{it} \quad (4)$$

In this specification, the focus is still on the logarithms of both per capita GDP, denoted by yit, and per capita of the emission or environmental degradation index, denoted by eit. Within this framework and in this paper i = 1, . . . , N indicates the country and t = 1, . . . , T is the time mark. In qualitative terms, similar results have also been obtained when using levels instead of logarithms (Wagner and M¨uller-F¨urstenberger, 2005). The stochastic error term of Equation (4) is denoted by μ_{it} with the appropriate assumptions concerning serial correlation. The first two terms on the right hand side in Equation (4), are intercept parameters that vary across countries (i), and years (t). The above formulation of the EKC posits a strong homogeneity assumption which implies that although environmental degradation may vary among countries at any given level of income, the income elasticity is the same for all countries at a given level of income. In a further strand, the time specific intercepts take care of time-varying variables that are omitted from the model, including stochastic shocks. Panel data analysis combine the features of both time series and cross-sectional analysis and are often specified to take care of fixed and random effects (for details, see Torres-Reyna, 2007). Fixed effects (FE) models treat α_i and γ_t as regression parameters, while random effects (RE) models treat them as components of the random disturbance.

In the literature, some theoretical discourses and studieshavealso included a cubic term in their estimations (see for example, Martinez-Zarzoso and Bengochea-Morancho, 2003; and Stern, 2014). In some of such specifications, the cubic model is cast as:

$$In(e_{it}) = \alpha_i + \gamma_{it} + \beta_1 In(y_{it}) + \beta_2 (In(y_{it}))^2 + \beta_3 (In(y_{it}))^3 + \mu_{it} \quad (5)$$

If β_3>0 in equation (5), this would be symptomatic of an N-shaped curve.In modelling the EKC relationship, Shafik (1994) expands the variables considered; thus suggesting that income is only one of the several factors which help to determine declining environmental quality generally. Other determinants of environmental quality in any country according toShafik are: 1) endowment such as climate or location; 2) the structure of production, urbanization, and consumption patterns of private goods, 3) exogenous factors such as technology that are available to all countries but change over time; and 4) policies that reflect social decisions about the provision of environmental public goods depending on institutions. Khanna (2002) also identifies such other critical factors that may influence the EKC existence as race, education, population density, housing tenure and the structural composition of the workforce.

In the strict case, establishing an EKC in the presence of other moderate factors provides a more convincing basis for validation of the hypothesis. We therefore experiment by expanding the basic model to include such factors as population density (PDEN), trade openness (TPN), and political economy (POEC). The higher the population density, the greater will be the intensity of pollution, as well as the pressure brought to bear on environmental services and resources. If the cubic term in Equation (5) is dropped, for simplicity and building on Levinson (2000) micro-foundation, the estimable equation is,

$$In(e_{it}) = \alpha_i + \gamma_{it} + \beta_1 In(y_{it}) + \beta_2 (In(y_{it}))^2 + \varphi_j \sum_{j=1}^{n} (In(X_{it}))^3 + \mu_{it} \qquad (6)$$

where,

X = vector of other explanatory variables. The basic estimable model for theanalysis can be concisely summarized as follows:

$$e = \alpha + \sum_{j=1}^{p} \beta_j X_j + \varepsilon, \qquad (7)$$

5.2 Sources of the Data

The data for the two indicators of environmental quality and other variables used in study are obtained from the World Bank (2012, 2013) source, *World Development Indicators;*and Smith, et.al. (2011), *Anthropogenic Sulfur Dioxide Emissions*: 1850–2005; and Marshall and Jaggers (2014), *Polity IV*. The African Development Bank’s publication, *Gender, Poverty and Environmental Indicators on African Countries* was used to complement some gaps in the data series. The definition of variables and their sources are summarized in Table 2.

5.3 Description of the Data

Issues on the time series properties of the variables are highlighted in sub-section 6.1, while the ECOWAS countries used in the analysis are presented in Table 3. The time frame for the analysis is influenced by data availability and consistency.

5.3.1 Sulfur dioxide (SO_2)

A consistent annual data series for SO_2 is available for 6 ECOWAS countries for the period 1960 – 2005, as indicated in Table 3. This makes a total of 46 observations for each ECOWAS country, and total balanced panel observations of 276 for the selected ECOWAS countries included in the sample. SO_2 emission on the average has been on the decline in the ECOWAS countries included in the study sample over time. Data on Sulfur Dioxide measured in Gigagrams of $SO_2$was collected from Smith, et.al, (2011).

5.3.2 Carbon dioxide (CO_2)

The CO_2 variable for all countries used in the study is measured in metric tons per capita/per annum in order to adjust for the population size of the countries used for the analysis. ECOWAS member average per capita carbon dioxide emissions range from 0.05 tons to 0.59 tons for Mali and Nigeria respectively. CO_2 data was collected for the period 1965 – 2009 for the twelve selected countries used in the analysis; thus making a total of 45 cross-sectional observations for each country and total balanced panel observations of 540.

The total per capita CO_2 for the twelve ECOWAS states is 5.35; this is about four times less than the US average and equal to average total emissions of Canada per annum. The relatively low per capita CO_2 emissions for the ECOWAS countries would obviously suggest that these levels should sustained by increasingly enhancing other ways of reducing emissions, for example through the use of environmental regulations. CO_2 emissions data was obtained from the World Bank, *World Development Indicators*, 2013.

5.3.3 Income per capita (y)

Among the numerous variables that affect per capita carbon dioxide production, per capita income is the factor which has prompted the largest amount of theoretical and empirical analysis. Our measure of income per capita is GDP per capita at constant prices (US 2000) since this measure of GDP is more reliable and available than measure of GNP and both measures are highly correlated. GDP is even more relevant to developing countries than Gross National Product (GNP) as measure of output. There is an abundance of economic literature and empirical support of the EKC for series of pollutants. Economic Growth and the Environment by Grossman and Krueger (1995) formed the fundamental basis for many econometric tests of the EKC done over time (Peterson, 2009).

5.3.4 Population density

Population density is measured as people per sq. km of land. The supposition as earlier noted is that countries with less dense, dispersed populations emit high levels of CO_2, due to high transportation costs (Neumayer, 2003; Emrath, 2008; Grazi, 2008; Peterson, 2009). In urban areas where the population is denser, on the other hand, there is tendency to produce relatively less CO_2, as people travel less distance and may make use of public transportation. The variable may have ambiguous effects as some have also argued that densely populated areas will make for greater use of coal and non-commercial fuels (Panayotou, 1997) and people exerting pressure more on economic and environmental resources. Population density data is extracted from the World Bank (2013) data set.

5.3.5 Openness

Openness is proxied as trade (% GDP) and is measured in this instance as the ratio of the sum of exports and imports to the nominal GDP. Trade as suggested in the literature is a major determinant of international technology adoption and diffusion. This occurs through imports of intermediate input, learning-by-exporting experience, foreign direct investment (FDI), communication, etc (Kinda, 2011). These processes encourage the use of modern technology that promotes pollution abatement. The trade (% GDP) data is obtained from the World Bank, *World Development Indicators* (2013) data set

5.3.6 Population growth

Population growth may have a result in growth of emissions (independently of the growth in per capita incomes) via the demand for public goods that are pollution-intensive, such as infrastructure and defense, as argued, for example, by Ravallion et al (1997) and (Mitsis, 2012).

Population growth statistics for the selected countries show that the average growth rate in the region to be 4.93%. This is explained by the pollution concentration growth of 7.2%, 4.07%, 6.44%, 2.96%, 3.53 % and 5.04% of Togo, Senegal, Nigeria, Ghana, Cote d'Ivoire and Benin respectively. It is also noted that more densely populated countries relatively emit higher levels of SO_2 concentration.

5.3.7 Polity variable

The polity variable captures the quality of institutions and the data is obtained from Marshall, and Jaggers (2014), *Polity IV*. Polity IV contains, amongst many other variables, yearly composite indicators measuring both "institutionalized democracy" and "autocracy". A summary "polity" measure is then defined as the difference between the democracy and autocracy scores, with 10 indicating "strongly democratic" and –10 indicating "strongly autocratic" Fazin and Bond (2004). The specification assumes that the quality of institutions, political regime and openness of the state to environmental preferences of the public can be captured using this index. The relationship between environmental quality and economic growth is consummated with political institutions in sharpening policy formulation. As often aptly underscored, "*The connection between environmental protection and civil and political rights is a close one. As a general rule, political and civil liberties are instrumentally powerful in protecting the environmental resource-base, at least when compared with absence of such liberties in countries run by authoritarian regimes"* (Dasgupta and Maler, 1995:2412). During the period under review, most of the countries in the ECOWAS region were either under authoritarian regimes or just emerging from civil crises.

6. Empirical Results

6.1 Time-Series Properties of the data

As a first step to estimating the relevant equations, a panel unit root tests are performed for each of the two pollutants and the underlying income covariates using panel unit root test and possibly the panel cointegration test. The frameworks for implementation of unit root tests in panel data are credited to Levin, Lin and Chu, 2002; Breitung, 2000; Im, Pasaran and Shin, 2003; Maddala and Wu, 1999 and Choi, 2001 and Hadri, 2000. Utilizing series of these tests, though relatively, proffers the possibility of improving on the weaknesses such as low-power and large-size distortions that may be associated with a single time series tests. As has been argued elsewhere, the EKC hypothesis is a non-linear function of income, thus making it inappropriate to subject it to panel unit root tests and possibly a waste (Coplien, 2014). However, Perman and Stern (2003) had argued earlier that such non-linear function can be analysed using linear cointegration methods. The linear cointegration method further suffers another drawback in the EKC relation as no cointegration can be expected between income and income squared. Again Perman and Stern (2003) argued that cointegration test in this circumstance should be analysed from the perspective that the relation is between emissions and the two variables not for a relation between the two income variables themselves. Others who have joined in this debate in recent times are Holy (2015), Warne (2014) among others. In order not to be enmeshed in the ensuing debate and attendant controversies, we have systematically in this study followed the standard practice of analyzing EKC panel dataset without testing for the time-series properties of the data panel cointegration. This is reserved for future application.

6.2. Panel FE, RE and OLS estimates for SO_2

The variants regression approaches to the test of the EKC model using the quadratic form in the sulfur (SO_2) model are displayed in Tables 4, 5 and 6. The regressors here are the per capita income (Per capita GDP and its squares (Per capita GDP^2). These techniques of analysis enable us to test whether the economic growth and SO_2 emission consistently hold for the ECOWAS countries used in the panel.

All slope parameters are statistically significant at 5% as *'a priori'* expected and rightly signed; indicating that income per capita is an important factor in estimation of SO_2 emissions. The implication is that the EKC hypothesis holds for local pollutants such asSO_2.

Specifically, the random effect model displays similar results in terms of signs of coefficients. Income per capita and income per capita square coefficients are respectively 28.31 and -2.25 and are significant. However, effects of income per capita and per capita square appeared to have greater impacts in the random effect model. The coefficients of determination are not to be worried about as they give highly negligible explanatory power of the regressors. This may reflect the omission of other fundamental variables from the basic model. The panel OLS results are not different from the random effect model. However, as for the choice between the fixed and random effects which becomes academic in a situation such as this, the paper has identified itself with and accepted the results of the Fixed Effects because Random Effects models are generally considered inappropriate for most economic applications because nearly all economic cases encountered, the time-invariant component of the error term, α_i, is correlated with one or more of the independent variables, rendering the Fixed Effects more appropriate (Hilmer and Hilmer, 2014:387).

On the basis of the expected coefficients, the turning point of the income per capita of the chosen model (fixed effects) is estimated as: $\tau = \exp[-\beta_1/(2\beta_2)]$.The income per capita turning point of the SO_2FE model is about $5,650 dollars over the period and thus this is the income that exists at the inverted U-shaped EKC. The turning point value though on average ishigher than the region's average gross domestic product (GDP) per capita which ranges from USD 800 in Niger to USD 4,400 in Cape Verde, are not too distant away from current levels of income. This suggests thatregulation of this pollutant may not be very difficult to achieve if left to income alone and that current environmental policy action is required to stem emission.This result generally agrees with the findings of some earlier studies (for example, Stern 2004; Markandya, Golub and Galinator, 2006, Apergis and Ozturk, 2015, among others).

The robustness of the EKC hypothesis is examined by estimating the pooled panel cubic EKC using the FE, RE and OLS. The results are awful as they were not significant, though correctly signed. The behaviour of the augmented quadratic EKC results for SO_2 when other control variables were included in the analysis similarly indicates the existence of an inverted-U relationship with income. The parsimonious results are mostly devoid of insignificant variables. The GDP per capita has positive effect on SO_2 emission and statistically significant, while the parameter of the squared GDP per capita is negative and significant at 5 percent level.

The political institution variable (DEM) is not significantly different from zero and does not have the expected a priori constraining sign, suggesting that the period under review in the ECOWAS region may have been marred by political violence, civil wars and lack of political openness and public voice as attested to by the asymmetries reported in Figure 7. While rise in income alone is not enough to drive climate change policies, what may be playing out is that ECOWAS countries require higher levels of democratization in conjunction with improved behavior of other economic agents to mitigate rising emission as they move to the next stage of higher level of industrialization. The non-significance of this variable may suggest that other deliberative processes are required to address issues of environmental quality. Population density in ECOWAS countries tends to intensify pollution from SO_2concentration more than any other sources in the estimations, suggesting deliberate policy intervention in urban planning. As Figure 7 depicts, population density trends are on the increase in the ECOWAS region.

The openness variable, as trade literature suggests, is a major determinant of international technology adoption and diffusion. This variable has a positive, significant impact on emissions with a coefficient greater than zero; implying a monotonically increasing trend connoting that increasing trade is accompanied by a rise in the level of the emission. This evidence gives credence to the pollution haven hypothesis which suggests that developing countries are the destinations for dirty industries or dumping sites of richer nations. Thus, the argument that trade through imports of intermediate input, learning-by-exporting experience, etc could encourage the use of modern technology that promotes pollution abatement increased use of resource efficiency may not necessarily be correct. Rather, the presence of externalities and trade openness could inhibit environmental quality and sustainable development.

6.3. Panel FE, RE and OLS estimates for CO_2

Tables 7, 8 and 9 report different variants of the panel fixed, random and the pooled OLS results for carbon dioxide (CO_2) emission. The main results of the CO_2 as in SO_2 are robust to specifications of income per capita and income per capita square given that they have the expected signs (0.001 and -6.74E^-07) and significant at the conventional level. Consequently, it can be concluded that the behavior of CO_2, a measure of global emission supports the EKC hypothesis of an inverted-U shaped relationship. The behavior of the other variables in the augmented estimations is not strikingly different from their SO_2 counterparts.

However, given that the polity variable which captures the quality of institutions, voice and accountability of the state to the environmental preferences of the populace is not significant, the CO_2 equation is re-estimated by interacting it with the income per capita variable. The underlining argument is that economic growth alone may be insufficient to improve environmental quality (Fazin and Bond, 2004). The augmented resultsfrom all the classes of estimations of this interaction report evidence of an unambiguous EKC relationship between income per capita, income per capita square and $CO_{2;}$ while CO_2 is negatively related to environmental polity variable (through the Per Capita GDP*Polity interaction variable). This affirmative finding that quality of public institutions matters in achieving environmental quality implies that deliberate and conscious choices of environmental policy efforts are required for cleaner environment as income per capita rises. This corroborates the findings for 14 Asian countries by Apergis and Ozturk (2014); who further suggest that the association of higher income per capita with better political systems and institutions would improve environmental quality, leading to less emission. The optimum turning point value of US$ 4.0475E-^{114} for CO_2which fell outside the original data is not strange with the EKC phenomenon (Stern, 2004). In addition, to strenuously argue for a higher turning point value will amount to "income determinism" (Unruh and Moomaw, 1998). CO_2turning points at best only represent the average among all the countries rather than a deterministic summit that marks the start of the downward phase of the curve (Poudel, Paudel, and Bhattarai, 2009). From the CO_2 augmented interactive results; the Hausman test favoured the FE model.This also curries the support of Hilmer and Hilmer (2014) as FE being more appropriate in economic applications.

The cubic polynomial model of $CO_2$where the income per capita appears in cubic form differs from the cubic form equation of the sulfur model. The expected sign (4.29 E^-09 and 4.40E^09) and significance of income per capita cube is really an appreciation of the 'N' shaped EKC hypothesis for the ECOWAS countries. The very rapid growing pattern of income seems to have further increased the degradation turning the scenario to the first case. This also points to the fact that higher income levels alone cannot automatically improve the environment (Beck and Joshi 2015), and as such, abatement effort by the ECOWAS governments against pollution is good to the environment.

7. Conclusions

In this study, the relationship between per capita income and environmental degradation in ECOWAS countries has been investigated, using longitudinal data spread generally between 1960 and 2009. Recognizing the often-cited income-environmental quality relationship, the specific objective is to estimate environmental Kuznets curves for two indicators of environmental quality, namely: sulfur dioxide(SO_2) and carbon dioxide (CO_2) and to establish whether the estimated relationships conform to the inverted U-shape hypothesis.

The results of the empirical investigation generally suggest the existence of environmental Kuznets curves for environmental quality indicators. Other factors such as population density; which is the most significant explanatory variable, openness, income-policy interaction variable are also found to affect environmental quality. Specifically, population density has a positive effect on environmental degradation, particularly for SO_2, while openness tends to reduce global pollution (CO_2). An N-shaped pollution – income curve was also indicated for CO_2– an indication that more stringent policy measures may be required to stem pollution from this source, as incomes rise to higher bounds. The N-shape is however, inverted for the case of SO_2.The turning points estimated for the different indicators of environmental quality are relatively low, thus suggesting a demonstration of the low level of industrial development in the sub-region occasioned by high incidence of poverty. Second, when these turnings are compared to evidence from extant literature on the environmental Kuznets curve, they suggest that ECOWAS countries may be turning the corner of the environmental Kuznets curve, much faster, and at lower levels of income than expected. Third, fuel processing is the major driver of anthropogenic SO_2 in the region (solely accounted forby Nigeria) followed by petroleum combustion. As for CO_2, the major driver is growth in rapid population followed by GDP.Nigeria accounts for77per cent of total CO_2 emissions due to growth in population and GDP, whilst these two factors contribute a total change of the 78 percent CO_2 emissions in the region. This calls for an urgent functional population policy intervention especially in Nigeria.

The polity variable which interacted significantly with the income variable to create the inverted-U shape EKC signals the importance of public institutions in environmental protection. Although, ECOWAS countries may have benefited from early learning effects and environmental awareness in their appreciation of various Protocols and Agreement they are committed to, there must be frantic efforts in the sub-region to enact and enforce enabling laws that would curtail firms' productive processes and consumption behaviour of other economic agents. To amplify this point further, policy makers in the sub-region must to be proactive to step up a sustainable roadmap and framework that would enhance emission abatement as the sub-region enters the phase of industrialization and may not need to wait for too long as the case with developed countries and developing Asia to improve environmental conditions. One of such ways is through the use of environmental tax instruments like fuel tax which has been found to be effective in some African countries (not ECOWAS countries).

The influence of other factors such as population density, population growth and trade openness on environmental quality provides justification for mainstreaming the environment into the entire process of planning for development in order to ensure environmental sustainability in the ECOWAS region. Although the estimates do not identify the underlying structural actions required to effectively tackle the reduction of these emissions particularly CO_2, the study at least has demonstrated that ECOWAS countries do not need to be fully developed like those of the West with high GDP per capita before they appreciate cleaner environment and implement environmental sustainability policies that should include population control measures. To further strengthen this, policy makers in ECOWAS countries must deliberately adopt energy policies that reduce carbon intensity in the match towards economic integration. Since fuel processing and fuel combustion are the major drivers of anthropogenic SO_2 in the region, fuel tax may be introduced in countries of the region as an environmental instrument to curb environmental emissions. Extended research will be undertaken to determine whether the use of such environmental tax instrument (fuel tax) in the region particularly Nigeria (which is seen to have a bearing impact in both the emissions and income covariates of the region) will be effective. In that research, issues of unit root in panel dataset for the EKC study of the ECOWAS will be taken into account in their modeling and inference.

8. References

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9. Tables and Figures

Table 1: Decomposition Analysis between 1994 - 1996 and 2004 – 2006 based on International Energy Agency (IEA) Data (million tonnes of CO_2)

Country	C_{eff}	S_{eff}	I_{eff}	G_{eff}	P_{eff}	ΔE	X(%)	V_{eff}
Benin	0.1	1.8	-0.2	0.2	0.4	2.3	-297	0.0
Ivory Coast	0.1	1.2	0.7	-0.3	1.0	2.7	-295	-0.8
Ghana	0.3	2.0	-0.7	1.1	1.2	3.9	-69	0.2
Nigeria	6.0	3.0	-8.0	8.0	11.0	20.0	-10	0.0
Senegal	0.1	0.6	-0.1	0.6	0.9	2.1	-42	0.1
Togo	0.05	-0.09	0.05	0.00	0.27	0.28	-4	0.0
Total	**6.65**	**8.51**	**-8.25**	**9.6**	**14.77**	**31.28**		

ΔE is change in a country's emission between the two periods. V_{eff} is conversion efficiency
Source: Extracted from Kojima and Bacon (2009).

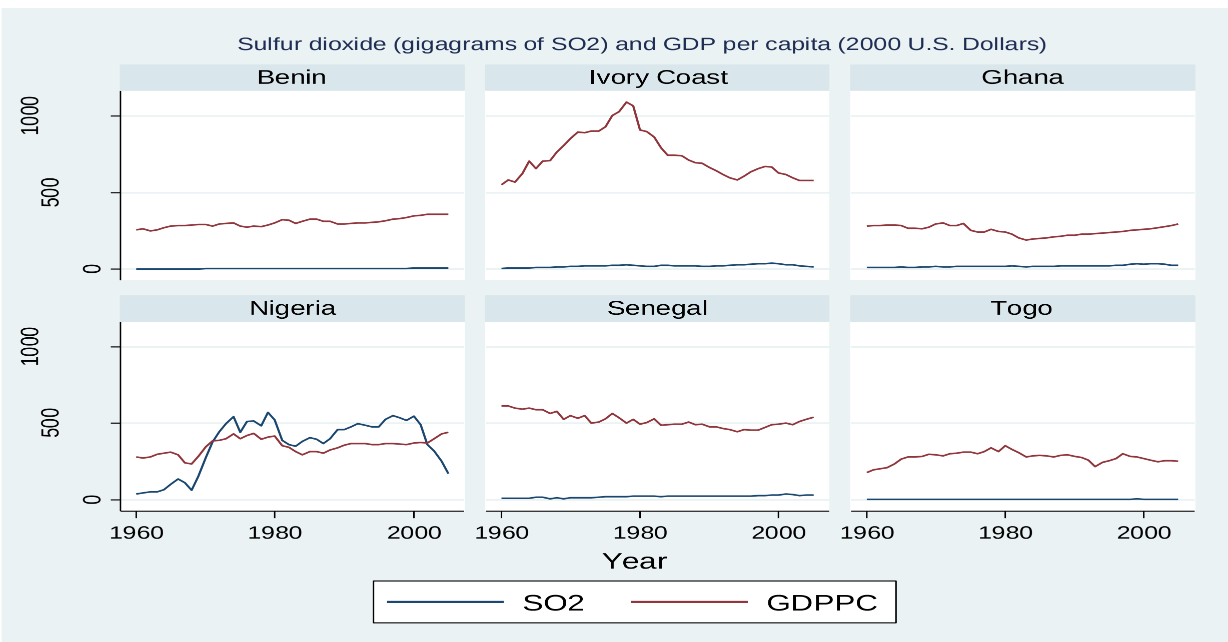

Figure 1: Graphs of Anthropogenic Sulfur Dioxide Emissions and GDP per capita of Selected ECOWAS in Gigagrams of SO_2 and 2000 U.S. Dollars respectively.

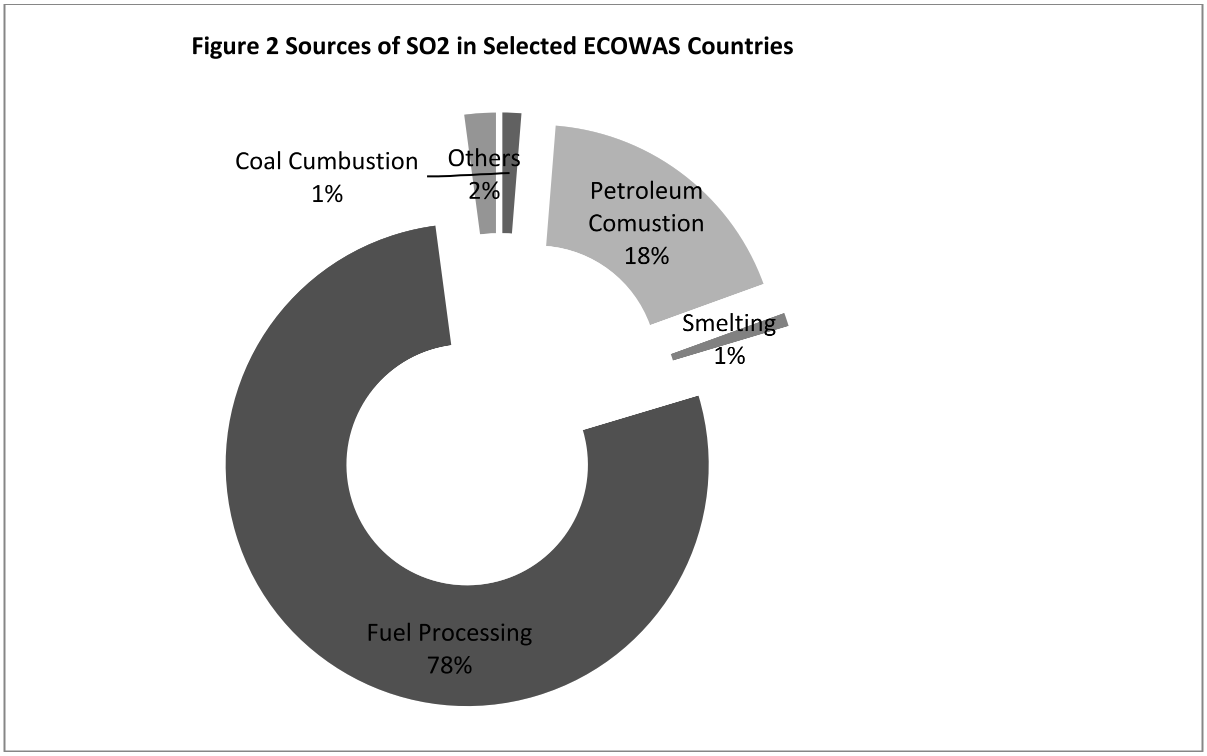

Figure 2: Sources of SO2 in Selected ECOWAS Countries

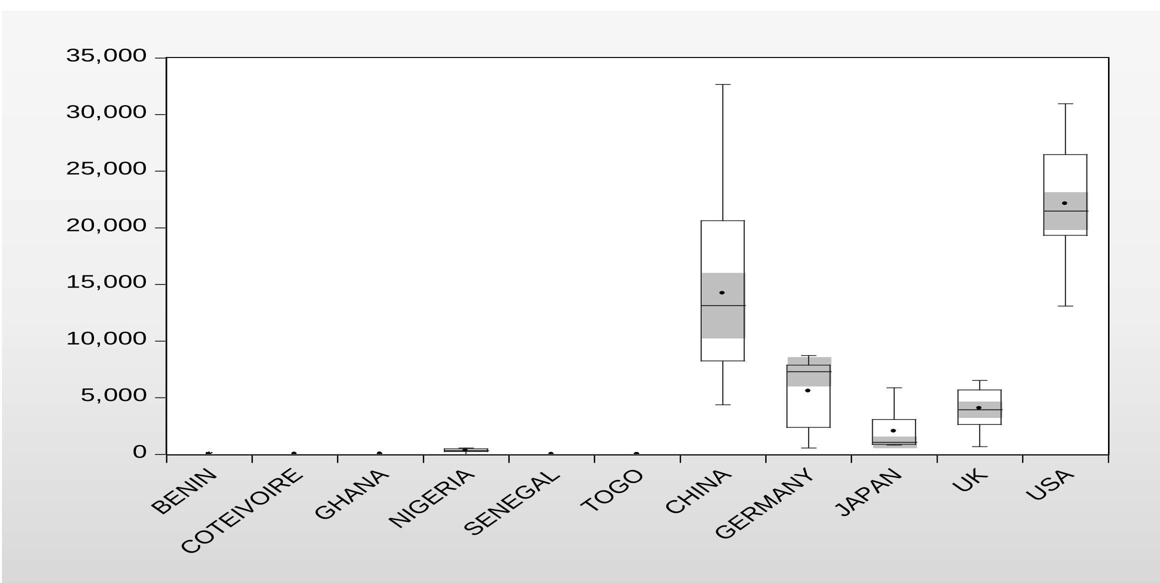

Figure 3: Box Plot of Anthropogenic Sulfur Dioxide Emissions of ECOWAS and Industrial Countries in Gigagrams of SO_2

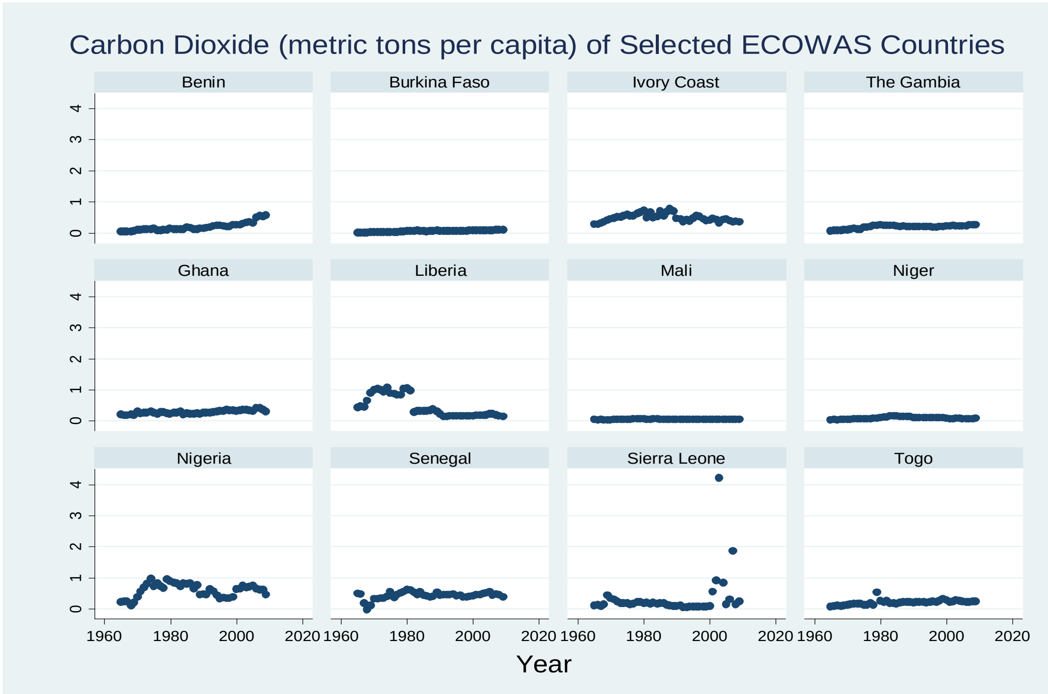

Figure 4: Graphs of Carbon Dioxide Emissions and GDP per capita of Selected ECOWAS Countries

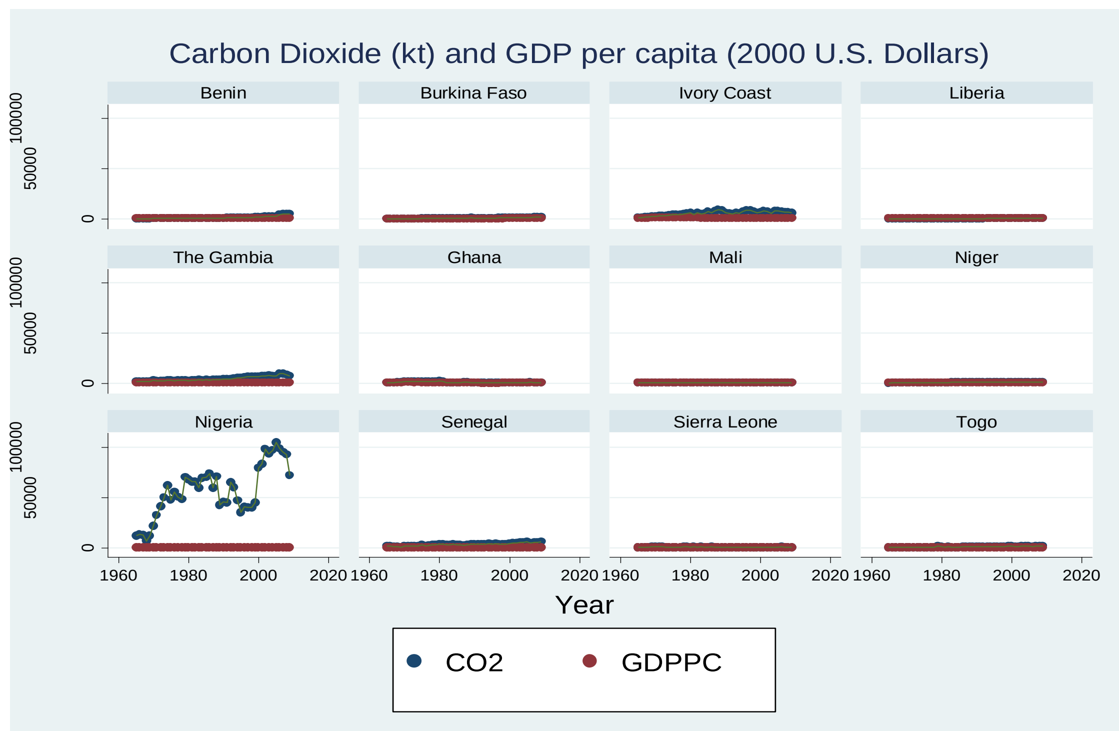

Figure 5: Graphs of Carbon Dioxide (kt) and GDP per capita of Selected ECOWAS Countries

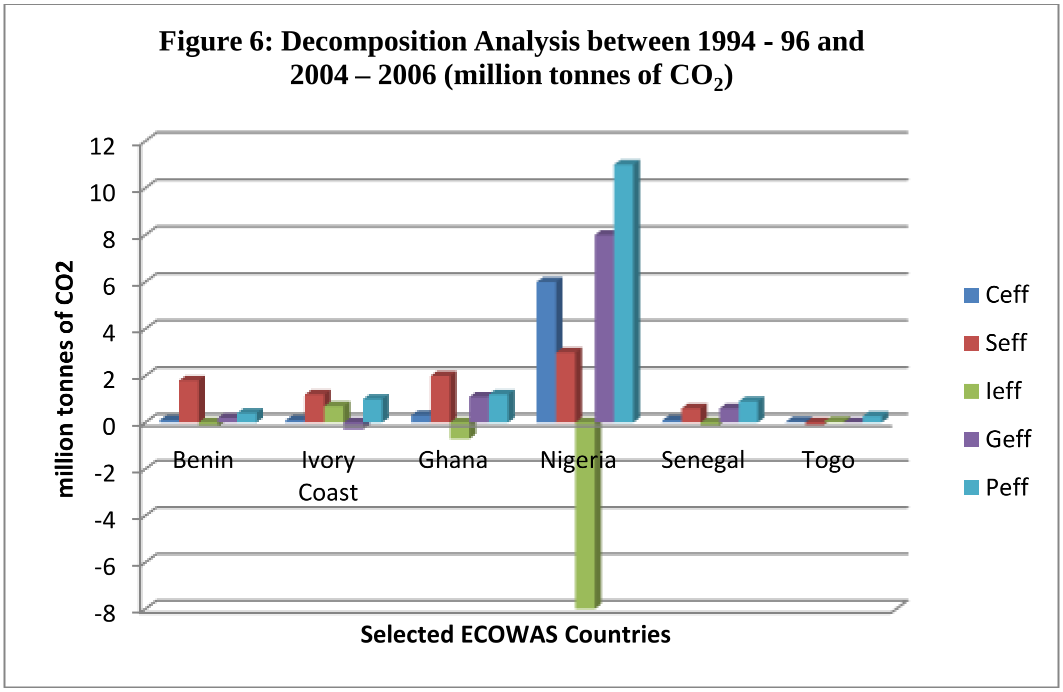

Figure 9: Decomposition Analysis between 1994 – 96 and 2004 – 2006 (million tones of CO_2)

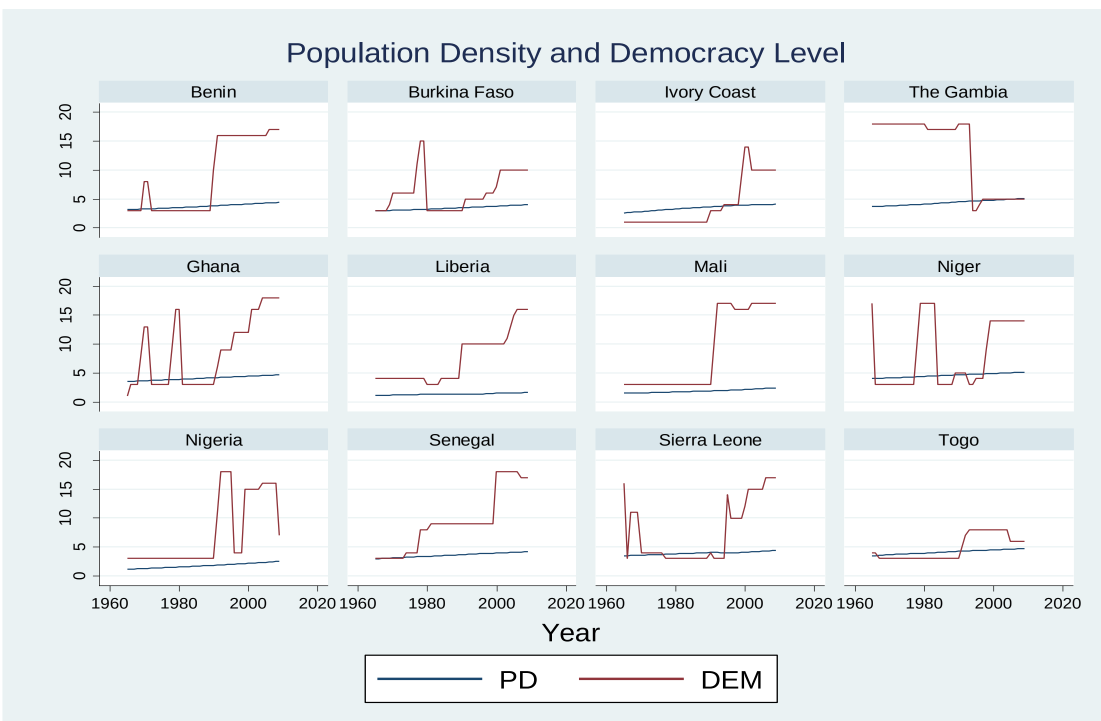

Figure 7: Population Density and Democracy Level of Selected ECOWAS Countries

Table 2: Definition of Variables and Sources of Data

Variable	**Description**	**Source**
GDP per capita (GDPPC)	GDP per capita (constant 2005 US$)	The World Bank, World Development Indicators, 2013
Sulfur Dioxide (SO_2)	Sulfur Dioxide measured Gigagrams of SO_2. This variable enters the estimable equation in form of concentrations.	Smith, et.al.' 2011
Carbon Dioxide (CO_2)	The CO_2 variable is measured in metric tons per capita/per annum. This variable enters the estimable equation in per capita form.	The World Bank, World Development Indicators, 2013
Democracy (DEM)	Polity2 indicator to examine the extent to which democracy level and stock have significant, independent effects on SO_2 and CO_2 emissions.	Polity IV, Marshall, M.G. and K. Jaggers (2014). Polity IV contains, amongst many other variables, yearly composite indicators measuring both "institutionalized democracy" and "autocracy". A summary "polity" measure is then defined as the difference between the democracy and autocracy scores, with 10 indicating "strongly democratic" and –10 indicating "strongly autocratic" Fazin and Bond (2004).
Population Growth (PG)	Population Growth Rates	The World Bank, World Development Indicators, 2013
Population Density (POD)	People per sq. km of land	The World Bank, World Development Indicators, 2013
Openness (OPN)	Trade (% GDP)	The World Bank, World Development Indicators, 2013

All independent variables are lagged by one year, except for democracy stock, which is lagged by two years (to separate it from the stock variable). Source: Marshall, M.G. and K. Jaggers Polity IV (2014).

Table 3: West African Countries covered in the Study for the Two Environmental Indicators (marked)

Country	Benin	Burkina Faso	Cote d'Ivoire	Gambia	Ghana	Liberia	Mali	Niger	Nigeria	Senegal	Sierra Leone	Togo
SO_2	*		*		*				*		*	*
CO_2	*	*	*	*	*	*	*	*	*	*	*	*

Sources: *World Development Indicators* (World Bank, 2013), Smith, et.al.(2011)

Table 4.Quadratic FE, RE and OLS estimates for ECOWAS countries (SO_2 as dependent variable)

Independent variables	FE	RE	OLS
Constant	-75.86(-3.20)	-85.89(-3.77)	-85.89(-4.01)**
GDPPC	25.02(3.20)**	28.31(3.75)**	28.31(3.99)**
$GDPPC^2$	-1.20 (3.06)**	-2.25(-3.84)**	-2.25(-3.84)
Hausman Test		0.23	
Fixed Red. Test	1.00		
R^{-2}	0.16	0.11	0.11
Turning Point	$5,650		
Observations	276	276	276

**Indicates significance at 5%. Figures in parentheses denote t-statistics

Table 5. Cubic FE, RE and OLS estimates for ECOWAS countries (SO_2 as dependent variable)

Independent. variables	FE	RE	OLS
Constant	102.92(0.36)	-16.71(-0.06)	-16.71(-0.07)
GDPPC	-63.72(-0.45)	-6.03(-0.05)	-6.03(-0.05)
$GDPPC^2$	12.66(0.54)	3.42(0.16)	3.42(0.17)
$GDPPC^3$	-0.80(-0.62)	-0.31(-0.26)	-0.31(-0.28)
Hausman Test		0.30	
Fixed Red.Test	1.00		
R^{-2}	0.16	0.11	0.11

Figures in parentheses denote *t*-statistics

Table 6. Augmented Parsimonious Quadratic FE, RE and OLS estimates for ECOWAS countries (SO_2 as dependent variable)

	FE	RE	OLS	FE	RE	OLS
Constant	-45.39 (-3.04)	-35.79 (-2.47)	-35.79 (-2.17) **	-12.79 (-0.74)	-8.05 (-2.93)**	-6.82 (-3.41)**
GDPPC	5.77 (2.17) **	5.90 (2.23) **	5.90 (2.08) **	3.59 (1.61)***	11.49 (2.13)**	11.49 (1.75)***
$GDPPC^2$	-0.10 (-3.24) **	-0.19 (-3.48) **	-0.19 (-3.42)	-0.58 (-1.64)***	-0.74 (-1.68)***	-0.74 (-1.93)***
DEM	0.06 (1.67)	0.02 (1.51)	0.02 (1.33)	-0.59 (-2.29)**	0.12 (1.67)***	
PG	-0.51 (-4.37)**	-0.59 (-5.47)**	-0.59 (-4.81)**			
POD	4.25 (21.53)**	2.96 (19.79)**	2.96 (17.40)**	4.22 (20.35)*	2.13 (16.56)*	2.31 (13.62)*
OPN	0.51 (4.88)**	0.21 (2.09)**	0.21 (1.84)**			
GDPPC*DEM				0.11 (2.49)**	-0.03 (-1.62)***	-0.03 (-1.66)***
Hausman Test	0.00				0.00	
Fixed Red Test		0			0	
R^{-2}	0.74	0.6	0.6			
SE	0.97	1.11	1.11	0.64	0.48	0.64
F-stat	12.55**	58.45*	58.45*	11.13**	51.73*	51.73*

*, ** and *** Indicate significance at 1%, 5% and 10% respectively. Figures in parentheses denote *t*-statistics

Table (7). Quadratic FE, RE and OLS estimates for ECOWAS countries (CO_2 as dependent variable)

	FE	RE	OLS
Constant	-0.05(-0.87)	-0.07(-1.22)	-0.07(-1.22)
GDPPC	0.001(4.34)**	0.001(4.78)**	0.001(4.78)**
$GDPPC^2$	$-6.74E^{-07}$	$-7.63E^{-07}$**	$-7.63E^{-07}$**
Hausman Test		0.11	
Fixed Red Test	0.38		
R^{-2}	0.23	0.15	0.15

**Indicates significance at 5%. Figures in parentheses denote *t*-statistics

Table (8). Cubic FE, RE and OLS estimates for ECOWAS countries (CO_2 as dependent variable)

	FE	RE	OLS
Constant	-0.47(-3.91)	0.50(-4.26)	-0.50(-4.26)**
GDPPC	0.004(5.11)**	0.005(5.45)**	0.005(5.45)**
$GDPPC^2$	$-7.66E^{-06}$	$-7.97E^{-06}$**	$-7.97E^{-06}$**
$GDPPC^3$	$4.29E^{-09}$	$4.40E^{-09}$**	$4.40E^{-09}$**
Hausman Test		0.12	
Fixed Redundant Test	0.38		
R^{-2}	0.26	0.18	0.18
Turning Point	4.0475E^{-114}$		
Observations	540	540	540

**Indicates significance at 5%. Figures in parentheses denote *t*-statistics.

Table (9): Augmented Quadratic FE, RE and OLS estimates for ECOWAS countries (CO_2 as dependent variable)

	FE	RE	OLS	FE	RE	OLS
Constant	-0.15 (-1.95)	-0.11 (-1.60)	-0.11 (-1.60)	-0.36 (-3.34)**	-0.26 (-3.20)**	-0.26 (-3.49)**
GDPPC	0.001 (2.79)**	0.001 (2.31)**	0.001 (2.31)**	0.001 (4.57)*	0.001 (3.98)*	0.001 (3.97)*
$GDPPC^2$	$-3.05E^{-07}$ (-0.99)	$-2.24E^{-07}$ (-0.74)	$-2.24E^{-07}$ (-0.74)	$-8.94E^{-07}$ (-2.62)**	$-6.96E^{-07}$ (2.08)**	$-6.96E^{-07}$ (-2.07)**
DEM	0.003 (1.10)	0.002 (0.80)	0.002 (0.80)	0.03 (5.23)*	0.02 (4.63)*	0.02 (4.62)*
DUMCC	0.25 (2.66)**	0.02 (0.74)	0.02 (0.74)			
OPN	-0.004 (-3.93)**	-0.003(-3.23)**	-0.003 (-3.23)**			
POD	-0.003 (5.64)**	0.002 (5.86)**	0002 (5.86)**	0.002 (6.20)*	0.002 (6.24)*	0.002 (6.22)*
PG	0.044 (2.36)**	0.06 (3.55)**	0.06 (3.55)**			
GDPPC*DEM				-7.73 (-5.64)*	-6.03^{E-05} (-4.88)*	-6.03 (-4.86)*
Hausman Test		0.00			0.02	
Fixed Red. Test	0.38					
R^{-2}	0.23	0.26	0.26	0.25	0.24	0.24
F-stat	3.9***	22.31**	22.31**	4.11***	30.82**	30.81**

*, ** and *** Indicate significance at 1%, 5% and 10% respectively. Figures in parentheses denote *t*-statistics.

Appendix 1

Table A1: Selected Studies on the Environmental Kuznets Curve

Authors	Time Period	Countries/Cities	Estimation Methods	Other Variables used	Findings
+Grossman and Krueger (1991)	1977, 1982, 1988	27-52 cities in 14-32 countries,	Panel data (Random effect)		First paper discussing the pollution-income relationship. Peak: $5000 Trough: $14000 (1985 USD).N curve
+Panayotou (1993)	1982-1994	55 developed and developing countries,	OLS	Population density	Inverted U. $3137 (1990 USD, nominal exchange rate) . First paper coined the pollution-income relationship by Environmental Kuznets Curve
+Selden and Song (1994)	1973-1975, 1979-1981, 1982-1984	30 countries (22 high-income, 6 middle-income and 2 low-income countries),	Panel data estimators (pooling, fixed and random effect)	Population density and period fixed effect	Inverted U curve OLS: no results FE:$8916-8709 ; RE: $10500 (1985 USD). Although find EKC, the authors believe the total emission will not decrease in very long term, as most of the population are living in the relatively poor countries
+Carson et al. (1997)	1990	US	OLS for cross-country data	Population density, percentage of urban population	Monotonically decreasing relationship. It is more interesting to see percentage change instead of absolute change of emission in EKC studies as different initial pollution situation induce difficulties of different level in pollution reduction
+De Bruyn et al. (1998)	1960-1993	4 countries, Netherlands, UK, USA and Western Germany,	OLS	Composition changes, energy price, economic growth path,	EKC does not generally fit for all countries, each country has its own technological, structural, energy price and economic growth path, so specific emission situation
+Perman and Stern (1999)	1960-1990	74 countries (25 developed and 49 developing countries)	Unit Roots and cointegration		Each country has its EKC curve, monotonically increasing

+Dinda et al. (2000)	1979-1982, 1983-1986 and 1987-1990	39 cities in 33 countries. 6 low-income, 11 middle-income and 16 high-income countries	OLS and least absolute error method	Sectoral composition (capital abundance, K/L), growth rate and time effect, distinguishing site characters (commercial, residential, etc.)	U curve. Trough: $12500 (1985 USD). Study includes the scale, composition and technique effects defined by Grossman (1995) into estimation of EKC curve
*Stern and Common, 2001	1960-90	73 developed and developing countries	Time and country effects		$101166
++Bartoszczuk et al. (2002)	1960-1996	Developed European countries	Agent based model	Per capita CO2 emissions, GDP per capita	Hesitant agreement with EKC. Turning points vary between countries.
+Cole and Elliott (2003)	1975-1990	26 countries	Panel data estimator (Fixed and random effect),	Trade impact, relative capital abundance (K/L), multiplicative terms between trade and other determinants of emission, GINI, literacy rate	Inverted U or N curve Global data: FE: $5367-$7483; RE: $8406-11168. Only OECD: $5431-$10521.
++Martinez-Zarzoso and Bengochea-Morancho (2004)	1975-1998	22 OECD countries	Pooled mean group estimator	CO2 emissions per capita, GDP per capita 1993 PPP)	N-shape EKC for majority of countries Turning point: $4914-$18364.
++Focacci (2005)	1975-1997, except India 1970-1997	Brazil, India, China	Macroeconomic indicators	CO2 emissions levels, per capita GDP, energy intensity	EKC doesn’t hold true for developing countries
++Vehmas et al. (2007)	1980-2000	EU countries	Linking analysis	Domestic extraction (DE), Direct Material Input (DMI), Domestic Material Consumption (DMC), Physical Trade Balance (PTB)	Some support for the existence of the EKC.
++Song et al. (2008)	1985-2005	China (29 Provinces)	Dynamic OLS and within OLS	GDP per capita, waste gas emissions per capita, solid wastes generated per capita, waste water emissions per capita	Inverse U-shape between per capita pollution and per capita GDP for waste gas emissions (turning point: 29017 yuan) and solid wastes (turning point: 9705 yuan). Inverse N-shape for waste water (turning point: 28296 yuan).

**Aslanidis and Iranzo (2009)	1971-1997	77 non-OECD countries	Smooth transition regression models		Positive but at a slower rate after some income threshold
++Kunnas and Myllyntaus (2010)	1950-2001	Finland	Generalised least squares (GLS)	Per capita GDP, SO2 emissions per capita	Inverted U-shape curve, with a turning point of $13000, at 37kg.
++Orubu and Omotor (2011)	SPM: 1990- 2002, OWP: 1980- 2002	SPM:47 African countries, OWP:6 African countries	Ordinary Least Squares (OLS), Random Effects (RE), Fixed Effects (FE)	Suspended particle matter (SPM), Organic water pollutants (OWP), per capita income, population density, education	SPM: inverted U-shape exists, thus supporting EKC hypothesis. Turning point: $84.32-$366.39. OWP: Results mixed. OLS-conventional EKC (turning point $739.93), FE and RE-U-shape EKC (turning point $822.71-$2030.81), Cubic form-N-shaped EKC (turning point $133.91-$232.42). Evidence more in favour of rising pollution as per capita income increases.
++Ahmed and Long (2012)	1971-2008	Pakistan	ARDL bounds	Per capita CO2 emissions, per capita real GDP, energy consumption per capita, trade openness ration, population growth	Confirms inverted U-shaped EKC in long-run.
++Borhan and Ahmed (2012)	1996-2006	Malaysia	Two stage least squares (2SLS)	Biochemical Oxygen demand (BOD), Cadmium (CD), Arsenic (AS)	The EKC relationship is found to exist for BOD and GDP per capita.
++Kohler (2013)	1960-2009	South Africa	ARDL, Granger causality tests, Impulse response (IR)	commercial energy use per capita, foreign trade	Long-run: energy consumption, income, foreign trade, squared income all CO2. IRV: income has no effect on CO2.
++Shahbaz et al. (2013)	1980-2010	Romania	ARDL bounds	Energy emissions per capita, energy consumption per capita	Confirms EKC in both long-run and short-run.

Abstracted from:
*David I. Stern (2003). The Environmental Kuznets Curve. International Society for Ecological Economics Internet Encyclopaedia of Ecological Economics
** Aslandis, N. (2009) Environmental Kuznets Curve for Carbon Emissions: A Critical Survey. Fondazione Eni Enrico Mattei, Nota Di Lavoro 75.
+ He, J. (2007). Is the Environmental Kuznets Curve hypothesis valid for developing countries? A survey. Cahier de recherche Working Paper 07-03
++ Inglesi-Lotz, R. and J. Bohlmann (2014). Environmental Kuznets curve in South Africa: To confirm or not to confirm?