Journal of Environmental Policy & Planning
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/cjoe20

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Published online: 27 Jan 2014.

Journal of Environmental Policy & Planning, 2014
http://dx.doi.org/10.1080/1523908X.2013.867802

Beyond the Environmental Kuznets Curve in Africa: Evidence from Panel Cointegration

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Abstract *The main objective of this study is to establish the applicability of the environmental Kuznets curve (EKC) hypothesis in explaining the relationship between environmental pollution and development in Africa. The EKC has been used to explain such relationships in a variety of contexts, yet rarely applied in Africa, despite it hosting both the poorest countries in the world, 60% of those with extreme environmental pollution vulnerability and having a distinct socio-economic and institutional profile that tests the validity of such a model. This paper describes an empirical model that applies the EKC hypothesis and its modifications to 50 African countries, using data from 1995–2010. The empirical analysis suggests that there is a long-term relationship between CO_2 and particulate matter emissions with per capita income and other variables, including institutional factors and trade, leading to specific recommendations on future strategies for sustainable development in an African context.*

Key Words: CO_2 emissions, environmental Kuznets curve, environmental pollution, institutions, panel cointegration
JEL Classification: N57, O13, Q16, Q17

1. Introduction

The environmental Kuznets curve (EKC) hypothesis has the main maxim that there is the existence of an inverted U-shaped curve between environmental pollution and economic development (Stanton, 2012). It also maintains that at early stages of economic growth, environmental degradation and pollution will increase at an increasing rate. However, after some threshold of economic development, the trend tends to reverse, such that higher levels of economic growth

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will eventually lead to environmental improvement (Grossman & Krueger, 1991; Stern, 2004). This is based on the fact that as an economy develops, it is able to adopt and adapt environmentally friendly productive processes, which can mitigate environmental pollution. Furthermore, a more economically developed country can afford the technology and institutional capacity that will result in the reduction of environmental pollution, much more than less-developed economies.

The EKC model has been criticized from a variety of perspectives, including the econometric component of its assumptions. Among the prominent criticisms is the question regarding the presence of a long-run stochastic trend between the baseline variables of the EKC model. Stern (2010) explained that the traditional EKC model did not take into account the unit-root properties of the variables. In addition, the variations in the relationship between the variables over time were not considered. Taking this into consideration, some studies have attempted to (in) validate the model using a number of techniques. Popular among these studies include Perman and Stern (2003, p. 325), who based their conclusions on the estimation of the EKC model using data for 74 countries. They argued that there is a 'doubt on the general applicability of EKC'; this is because even when cointegration relationship was established between the variables, many of the relationships for individual countries were not concave. However, their panel estimation established a stochastic trend between the baseline EKC variables.

This current paper re-examined the EKC model using the panel cointegration approach for a sample of African countries. This is with a view to providing further analysis on the applicability of the EKC model using mainly African samples, unlike other studies such as Perman and Stern (2003) that used 74 countries around the world, excluding former Soviet Union and some Eastern European countries. Though African countries are classified as developing, they have different *stories* that can affect the estimations from their combinations with other developing countries. The diversity in their social, economic, institutional and political frameworks means that they have different challenges and opportunities that can inform the outcome of their environment. If these items are controlled for when testing the EKC model with robust econometric techniques, then the literature on EKC will experience a broader discussion. A brief scan of literature reveals that there is dearth of empirical studies of EKC within the African context, highlighting the need for the present study.

This study also extends the work on EKC by not only adding other explanatory variables (e.g. institutional quality and trade) to the traditional EKC variables but goes further to examine the selected African countries based on income groups and natural resources (oil-producing attributes). Natural resources in Africa have for a long time co-existed with environmental pollution. The exploitation of natural resources at an increasing rate as well as the abuse of natural vegetation has led to the production and accumulation of greenhouse gases, hence the global warming. The case of the Niger Delta region of Nigeria is very illustrative, where oil exploitation and gas flaring into the atmosphere has brought about environmental consequences such as soil degradation, water pollution and air pollution. The increased environmental pollution poses huge risks for sustainable development in the future yet rarely related to the EKC hypothesis.

The issue of environmental concern and testing the validity of the EKC model in Africa is vital for various reasons. First, for policy actions, there is the need to understand the applicability of this model in the African context. Second, anecdotal evidence suggests that African countries are more prone to environmental pollution as a result of increasing rate of poverty. For instance, the trend of environmental pollution using Carbon IV Oxide emissions (CO_2 emissions) *per capita* for Africa has increased markedly from −7.40% in 1980 to 6.38% in 2008; while the *per capita* income increased from −3.75% to 4.02% for the same period (World Bank, 2012). Moreover, over 60% of countries in the world that experienced extreme environmental pollution are located in Africa (Maplecroft, 2011; Osabuohien *et al.*, 2013). The above suggests the existence of a direct relationship between the indicators of economic growth and environmental pollution, on one hand, and the possibility of EKC, on the other. This requires further empirical clarification, which the current paper addresses.

The remainder of the study has five sections: following this introductory section is the background of the study, followed by literature review and analytical framework while the empirical model and the estimation technique were presented in the fourth section. The fifth section discusses the empirical results and the last section concludes with some policy recommendations.

2. Brief Background Information

In this section, we situate the condition of environmental pollution in Africa in relation to other regions of the world. The information in Table 1 includes CO_2 emissions and particulate matter concentrations that are below 10 μ in diameter (PM10). These forms of green house gases (GHGs) are regarded as the largest contributors to the share of total GHGs in the world (World Bank, 2007).

Table 1 records that the contribution of CO_2 emissions of African countries vis-a-vis the total CO_2 emissions of the world has consistently increased from 1.78% in 1971–1980 to 2.15% in 1991–2000 and further increased to 2.17% in 2001–2008. Comparing this magnitude of increase with the situation of other regions of the world reveals that Africa has not contributed much to the total world emissions. However, since the world is a global village, the deleterious effects are borne by all. Nonetheless, by examining the trend of CO_2 emissions (kt) in Africa, Figure 1 reveals that the CO_2 emission is on a consistent increase over the period. The value has increased by about 451% between 1960 and 2008.

Other sources of pollution using the PMs' concentration in the atmosphere across sampled regions of the world were also examined as presented in

Table 1. CO_2 emissions (kt) as percentage contribution to the world CO_2 emissions

Regions	1971–1980	1981–1990	1991–2000	2001–2008
East Asia and Pacific	15.65	19.52	25.55	30.84
Europe and Central Asia	n.a	n.a.	29.71	23.77
Latin America and Caribbean	4.00	4.66	5.16	5.18
Middle East North Africa	2.94	3.88	5.20	6.09
South Asia	1.75	2.90	4.59	5.58
Africa[a]	1.78	2.27	2.15	2.17

Note: n.a. indicates not available.
Source: Authors' computations from World Bank (2012).
[a]Africa here comprises mainly sub-Saharan African (SSA) countries. Australia and North America are not included because they were not so classified like other regions in the data source.

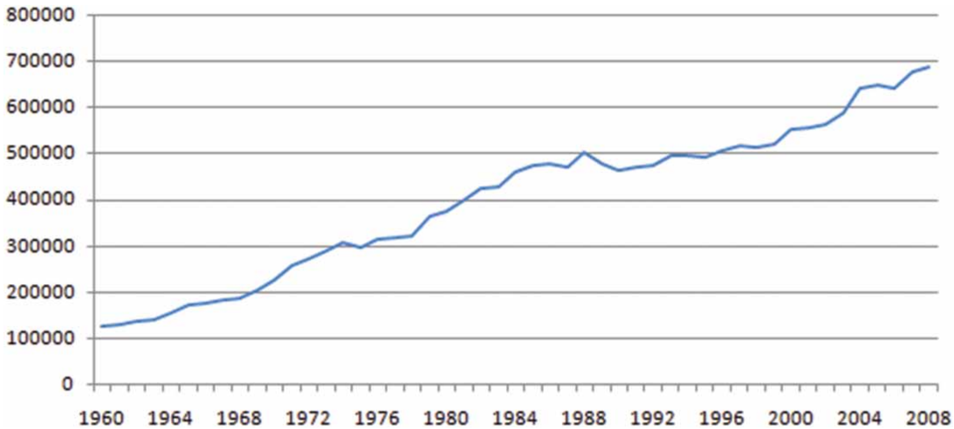

Figure 1. CO_2 emissions (kt) in Africa (1960–2008).
Source: Authors' computation from World Bank (2012).

Table 2. From the table, Africa has witnessed relatively higher emissions of PMs, especially during the period 1991–1995 (109.26 m^3). During this period, the world average was 74.53 m^3. The value for Africa reduced to 49.82 m^3 in 2006–2009, but has consistently remained higher than the world average. All through the period, Africa has remained on the higher echelons of regions exposed to this form of pollution.

We further examined the trend line between environmental pollution and the *per capita* income of African countries. This is presented in Figure 2 and it can be observed that a trend exists between the variables CO_2 and gross domestic product (GDP) *per capita*. From the figure, it is evidenced that the trend of CO_2 follows that of GDP *per capita*. The statistical significance of this trend is presented in the note to the figure and the relationship is significant at 1%. This implies that the trend between the two variables is significantly related and the coefficient of the relationship suggests that a change in *per capita* GDP will result in a significant change in CO_2 emissions.

Having observed the similarity in the trends between environmental pollution and *per capita* income in Africa, we question the validity of the EKC hypothesis in explaining this relationship. The empirical aspect of this study provides further clarifications.

Table 2. PMs atmospheric concentration micrograms per cubic metre

Regions	1991–1995	1996–2000	2001–2005	2006–2009
East Asia and Pacific	88.25	76.79	69.97	57.25
Europe and Central Asia	38.46	31.59	27.45	21.74
Latin America and Caribbean	50.66	43.43	38.68	31.84
Middle East North Africa	128.85	109.21	92.81	73.24
South Asia	127.15	111.79	91.00	71.46
Africa[a]	109.26	84.40	69.46	49.82
World	74.53	65.04	57.47	46.47

Source: Authors' computations from World Bank (2012).
[a]Africa here comprises mainly SSA countries. Australia and North America are not included because they were not so classified like other regions in the data source.

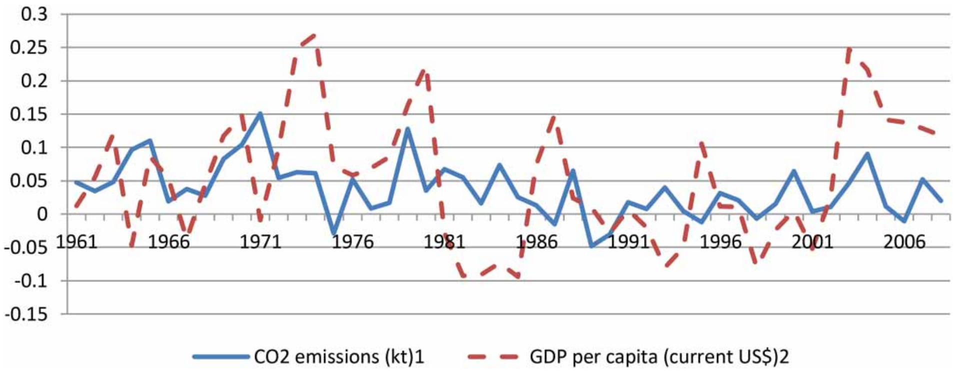

Figure 2. Trends in the growth rate of GDP *per capita* and CO_2 emissions in Africa.
Note: This is based on all African countries; the relationship between the variables is stated in the equation as: $CO_2 = 0.90 + \beta_2 1.16$GDP *per capita* + c; 1.16 is significant at 1%.
Source: Authors' computation from World Bank (2012).

3. Review of Literature and the Analytical Framework

3.1. *Literature Review*

Following the seminal work of Grossman and Krueger (1991), there have been appreciable research efforts on environmental quality and economic growth, particularly in developed countries, with limited works in Africa. The results from extant studies with respect to EKC have been mixed. Some scholars (Grossman & Krueger, 1991; Selden & Song, 1994) have found evidence supporting the EKC, while others hold a contrary view (Gershuny & Weber, 2009; Saboori & Soleymani, 2011).

The relationship between economic growth and environmental pollution is rather complex. The EKC offers some explanatory tool for shedding light on the interdependence between economic growth and its implication for environmental pollution. It suggests that as income increases, environment degeneration increases first at an increasing rate and then at a decreasing rate. Grossman (1995) noted that the inverted 'U-shaped' pattern in the EKC hypothesis is resulting from the joint effects of the scale of the economy, its composition and technology.

Traditionally, it was thought that the relationship between economic growth and environmental degradation was monotonic, despite little agreement on whether economic growth leads to environmental degradation or not. A number of empirical studies in the early 1990s found a non-monotonic, inverted-U relationship between a number of pollutants such as CO_2 and sulphur dioxide and income, therefore suggesting a changing relationship between the environment and growth along the course of economic development (Larson *et al.*, 2012). In addition, a dual relationship exists between sustainable development and climate change as concluded by the Intergovernmental Panel on Climate Change (2007) fourth assessment report.

The EKC hypothesis was attributed largely to behavioural factors: as income rises the effective demand for environmental quality rises and eventually overwhelms any scale effects of economic growth on pollution (Stern, 2004). At higher levels of economic development, there will be a structural change in the economy, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures. These can lead to a gradual decline of environmental degradation. Conversely, if there are no changes in the structure of technology or scale of the economy, there would be higher forms of environmental pollution from economic activities.

Some types of economic structure have been emphasized by some studies such as Ravallion *et al.* (2000), who pointed out that development processes that are essentially resource-driven will depend on how well a society manages its resources in order to avoid or mitigate pollution. Panayotou *et al.* (2000) investigate the role that policies and institutions play in influencing environmental quality and discovered that better governance and policies make a momentous improvement in environmental quality. Thus, policies and institutions that focus on development will also affect environmental pollution. The role of strengthened institutions in reducing the environmental impact of Multinational Corporations has recently been stressed in Osabuohien *et al.* (2013), that environmental hazard occurs at a decreasing rate when strong environmental policies are implemented.

Assessing the robustness of different parametric analyses conducted and using alternative emissions data, Galeotti *et al.* (2006) find that EKC does not depend on the source of data with respect to CO_2 and provide evidence of EKC for Organization for Economic Co-operation and Development (OECD) countries but not for non-OECD countries. Also Lipford and Yandle (2010), focusing on G8 and five developing countries, assess the relevance of EKC and their findings raised doubts about the feasibility of reducing global CO_2 emissions with improvement in income. Taguchi (2012) found that sulphur emissions follow the expected inverted-U shape while CO_2 tends to increase in line with increase in *per capita* income. Furthermore, Rothman (1998) using a variety of environmental indicators finds that CO_2 emissions and municipal waste do not tend to decline with increasing *per capita* income. Efforts to test the hypothesis using cross-sectional data have been criticized as misleading (Stern, 2004).

The trend of methods used in testing EKC has evolved from the simple quadratic functions used in early studies of Grossman and Krueger (1991) to the application of panel data[1] methods, as in Perman and Stern (2003). Perman and Stern employ panel unit root and cointegration tests and find that there is a long-run relationship between sulphur emissions and GDP *per capita*. Coondoo and Dinda (2002) used CO_2 and found similar results. Furthermore, Coondoo and Dinda found that in developed countries causality runs from emissions to income while in developing countries there is no significant relationship. Villanueva (2012), assessing the impact of institutional quality on the environment, using World Governance Indicators (WGI) of the World Bank, found support for EKC hypothesis using CO_2 emissions as a measure of environmental change for the period 1985–2005. The author concludes that institutional factors should be taken into account in policy-making, which has implications on environmental degradation. However, the author did not take into cognisance the issue of cointegration and unit root which establishes whether a long-run relationship exists. The present study differs by focusing on only African countries, including an additional variable, carrying out sub-sample analysis for oil producers and using a different technique—Panel Dynamic Ordinary Least Squares (PDOLS).

From the literature reviewed, the divergent views suggest there is a lack of consensus over the relevance of the EKC to geographic region or spatial scale. Similarly, there have been differing emphases on the role of other social, economic and institutional factors in determining the relationship between economic developments and environmental performance. The way in which these debates have drawn on the experience of developing countries, particularly Africa, has also been neglected and could therefore provide additional perspectives to this debate. This study aims to address this gap, by assessing the applicability of EKC in Africa, with an emphasis on exploring the role of institutions in reducing long-term pollution. Institutions have a relatively weak position in developing countries and especially in Africa. Lack of proper awareness and institutional mechanisms to address the causes of environmental pollution would be seen to have deteriorating effects on the development process. As estimated by Stern (2004), there will be at least 11% decline in per capital global consumption in the next two centuries compared to what would have been without climate change and the impact will differentially fall on the poor. This is of particular concern to African countries as nearly three-quarters of the extremely poor persons across the world (about 414 million) live in the continent of Africa (World Bank, 2013).

3.2. *Analytical Framework*

This paper is constructed around the analytical framework depicted in Figure 3. From the framework, we articulate that environmental pollution is mostly affected by economic activities. We therefore focus on economic income and the presence of natural resources, which are the major determinants of economic activities in most African countries particularly the oil-producing countries, where the oil sector accounts for a sizable proportion of their economy in terms of both revenue to the government and export 'basket'. Nigeria is a case in point, where oil constitutes over 90% of export earnings and 83% of federal government revenue (Export Import Bank, 2009). The broken line from income and natural resources to the box-minimal industrial activities implies that countries in this category experience minimal industrial activities as a result of low income and natural resources. Minimal industrial activities implies that the productive capacity of the country is rather low as a result of low income and/or low volume of natural resources to foster high industrialization and attraction of

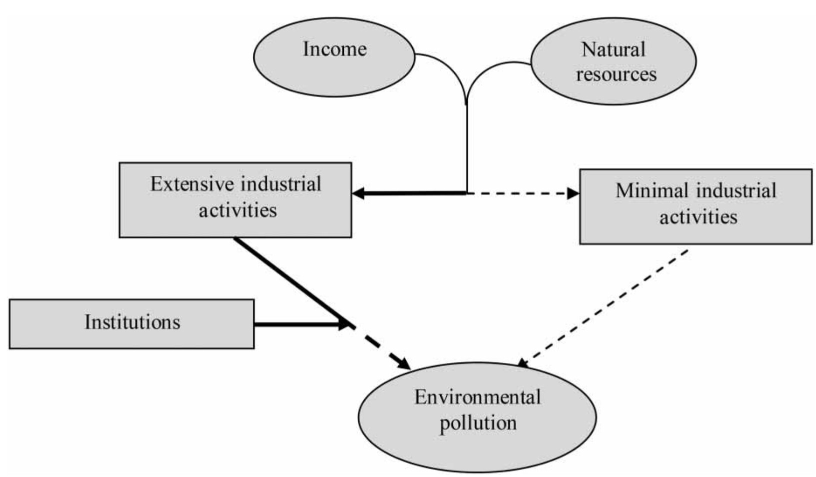

Figure 3. Analytical framework.

resource-seeking investors. For instance, the industrial activities in the Benin Republic cannot be compared with those of Nigeria due to difference in their level of income and natural resource endowments.

On the other hand, the thick line signifies countries that are permeated by more industrial activities.

In any case, no matter the extent of industrial activities, the environment is still at risk, because environmental pollution is affected by human activities. This is represented by the broken line and thick line flowing from the boxes to environmental pollution. The thick line signifies that the influence of more economic activities on the environment is more significant. However, the role of institutions is paramount in this case, as institutions can enhance environmental controls and responsibility despite the level of economic activities.[2] This is represented by the broken thick line. The argument is that with institutional strengthening, there will be policies to prohibit environmental pollution that includes CO_2 emissions and PM, particularly those from the industrial sector. Institutions will also help to curtail behaviours from the households as they seem to understand the need for better environmental practices. The example of managed and resourceful waste disposal in developed countries of Europe, where members of households and the general public are obliged to separate their domestic and official waste into designated containers, is instructive. This helps the process of better waste disposal and recycling for economic activities.

The above can be rooted in the cooperation between the regulative aspect of institutions (where the government puts in place a legal system and mechanisms of enforcement of policies) and the normative aspect of institutions (where other economic agents, e.g. individuals and firms, see the need to adhere to such policies). Kshetri (2012) discussed the role of regulative and normative institutions in relation to security and private matters in cloud computing. This kind of cooperation is essential to ensure better environmental quality particularly in Africa where institutional quality happens to be relatively low. Villanueva (2012) and Osabuohien *et al*. (2013) have echoed this point.

Based on the issues observed from the literature and the analytical framework, this study aims to extend the debate on the EKC in the following ways (i) the use of panel cointegration and the provision for diagnostic statistics for integration of variables, which helps to address some of the econometric concerns raised by Stern (2004); (ii) the use of sample involving only African countries and thus addressing the issue of regional differences that might arise when combining a group of developing countries from different parts of the world; and (iii) the inclusion of an additional environmental indicator, namely PM, to provide more robust and comparative analysis.

Further we consider oil-producing and non-oil-producing countries. It can be expected that in oil-producing countries the pollution will keep on increasing; however, in non-oil-producing countries heavy industrial production increases environmental pollution in early stages of development but with higher incomes the firms and governments have financial and institutional capacity that would enable them to *bargain* for a more environmentally friendly production process.

4. Research Method

The sample for this study comprise 50 African countries for the period 1995–2010. The countries and the period of study were selected based on data availability. The data are sourced from World Development Indicators (World Bank, 2012) and WGI (Kaufmann *et al.*, 2010). The selected countries with their respective summary statistics of the main variables are presented in Table 3.

The baseline EKC model is a simple quadratic equation that includes measures of income, squared value of income and environmental pollution. By applying the logarithmic transformation, the EKC model is presented as:

$$\mathrm{Ln}\left(\frac{E}{P}\right)_{it} = \alpha_i + \gamma_t + \beta_1 \ln\left(\frac{\mathrm{GDP}}{P}\right)_{it} + \beta_2 \left(\ln\left(\frac{\mathrm{GDP}}{P}\right)\right)^2_{it} + \varepsilon_{it}. \tag{1}$$

E indicates emissions and P population. α_i and γ_t are the intercept parameters which vary across countries or regions 'i' at time 't'. The rest of the variables in Equation (1) are the GDP *per capita* and its squared value. The inclusion of the squared value indicates a non-linear relationship.

In our econometric model, we extended the baseline EKC model by the inclusion of measures of institutional quality (Instq) and trade. The aim of this inclusion was to account for the influence of international trade and institutional quality on the environment. These variables are vital especially for Africa, since she is highly trade-dependent and the level of her institutional development is low compared to other regions of the world. Thus, the model for this study is expressed as:[3]

$$\mathrm{Clmg}_{it} = \alpha_0 + \alpha_1 y_{it} + \alpha_2 y^2_{it} + \alpha_3\,\mathrm{Instq}_{it} + \alpha_4\,\mathrm{Trade}_{it} + \varepsilon_t, \tag{2}$$

where Clmg_{it}: environmental pollution proxied as CO_2 emissions *per capita*. y: real *per capita* GDP. y^2: the square of real *per capita* GDP. Inst: institutional quality measured as the average value of rule of law (RL), regulatory quality (RQ) and government effectiveness (GE) computed from WGI. RL reflects the extent to which economic agents have confidence in and abide by the rules of society (e.g. quality of contract enforcement, property rights etc). RQ shows the ability of the government to formulate and implement sound policies and regulations that permit and promote private-sector development, while GE shows the quality of public services and governance. The values range from -2.5 (lowest) to 2.5 (highest). Trade: volume of trade measured as the ratio of trade (export and import) to GDP.[4] ε error term.

The estimation process involves the use of panel cointegration and vector autoregressive techniques. To test for the long-run relationship between economic variables, it is rational to assume that cross-section unit correlation exists (Alege & Osabuohien, 2013). Thus, the assumption of 'inertia within variables' may not be plausible. To account for this, some panel unit-root tests have been developed to examine the variability in the mean and variance in a series. Four of them were used in this study, namely Levin *et al.* (2002)-LLC, Breitung (2000), Im *et al.* (2003)-IPS and Fisher-type augmented Dickey Fuller (FADF). The first two assume a common unit-root process, while the others allow for individual unit-root processes.

Table 3. Mean of variables in the model across sampled countries

Country	Clmg	RL	RQ	GE	pgdp	Trade	Country	Clmg	RL	RQ	GE	pgdp	Trade
Algeria	3.11	−0.79	−0.71	−0.66	2640.69	59.56	Lesotho	0.00	−0.13	−0.55	−0.33	559.17	161.97
Angola	0.91	−1.45	−1.30	−1.20	1744.00	131.59	Libya	9.22	−0.86	−1.43	−1.05	7238.44	71.15
Benin	0.31	−0.47	−0.40	−0.43	510.40	43.09	Madagascar	0.11	−0.44	−1.58	−0.59	310.80	64.17
Botswana	2.29	0.61	0.61	0.55	4577.23	85.08	Malawi	0.08	−0.29	−0.41	−0.54	222.25	68.39
Burkina Faso	0.08	−0.49	−0.25	−0.67	333.41	35.58	Mali	0.05	−0.35	−0.39	−0.82	364.46	65.04
Burundi	0.04	−1.28	−1.30	−1.32	130.40	34.58	Mauritania	0.68	−0.62	−0.40	−0.48	704.21	98.69
Cameroon	0.25	−1.18	−0.80	−0.82	849.00	45.31	Mauritius	2.39	0.94	0.54	0.59	4892.48	122.76
Cape Verde	0.49	0.50	−0.20	0.12	1926.92	96.80	Morocco	1.28	−0.03	−0.17	−0.12	1799.85	65.84
Central African Republic	0.07	−1.47	−1.12	−1.46	338.37	37.27	Mozambique	0.08	−0.67	−0.43	−0.45	283.79	63.71
Chad	0.03	−1.26	−1.04	−1.16	395.30	82.60	Namibia	1.19	0.21	0.20	0.14	2959.01	95.92
Comoros	0.16	−1.06	−1.41	−1.57	534.90	53.54	Niger	0.08	−0.66	−0.51	−0.77	244.31	41.06
Congo, Dem. Rep.	0.05	−1.73	−1.63	−1.72	132.13	56.30	Nigeria	0.56	−1.26	−0.94	−0.98	655.79	74.84
Congo, Rep.	0.43	−1.30	−1.21	−1.26	1481.85	134.65	Rwanda	0.09	−0.87	−0.74	−0.56	303.32	34.76
Cote d'Ivoire	0.43	−1.31	−0.74	−0.99	872.82	80.54	Senegal	0.44	−0.19	−0.23	−0.23	726.10	32.94
Djibouti	0.59	−0.74	−0.75	−0.90	860.91	92.46	Seychelles	6.59	0.27	−0.56	0.12	8820.39	156.08
Egypt	2.06	−0.03	−0.33	−0.35	1486.76	50.64	Sierra Leone	0.20	−1.15	−1.13	−1.29	237.83	49.24
Equi. Guinea	4.76	−1.29	−1.44	−1.49	8898.83	156.38	South Africa	8.63	0.10	0.53	0.62	4320.51	55.29
Eritrea	0.15	−0.79	−1.65	−1.13	239.16	75.40	Sudan	0.22	−1.44	−1.33	−1.23	681.96	66.82
Ethiopia	0.07	−0.75	−1.05	−0.73	187.47	38.68	Swaziland	0.94	−0.71	−0.50	−0.77	2134.20	178.62
Gabon	0.12	−0.46	−0.32	−0.68	5686.98	94.86	Tanzania	0.11	−0.37	−0.42	−0.46	345.42	49.30
The Gambia	0.21	−0.20	−0.45	−0.60	349.54	96.06	Togo	0.25	−0.86	−0.75	−1.36	382.21	82.98
Ghana	0.36	−0.10	−0.15	−0.10	609.42	83.67	Tunisia	2.10	0.06	−0.01	0.46	2946.06	90.17
Guinea	0.15	−1.22	−0.89	−0.94	406.62	57.48	Uganda	0.07	−0.54	−0.05	−0.54	322.27	40.47
Guinea-Bissau	0.20	−1.30	−1.00	−1.13	316.77	65.50	Zambia	0.20	−0.52	−0.49	−0.83	602.88	70.67
Kenya	0.28	−0.94	−0.27	−0.58	528.44	59.08	Zimbabwe	1.00	−1.49	−1.81	−1.02	520.86	82.53

Notes: The mean of the variables for entire sampled countries (All) are: CO_2 emissions *per capita*—Clmg (1.08); RL (−0.65); RQ (−0.67); GE (−0.67); pgdp (1572.34); the ratio of trade to GDP—trade (76.60). The respective components of institutional quality (i.e. RL, RQ and GE) are used in this table to have impression on their respective values.
Source: Authors' computation using E-views 7.0.

The LLC approach assumes that the persistent parameters are common across the cross-sections, i.e. $p_i = p$ for all i from the following equation:

$$\Delta y_{it} = \alpha y_{it-1} + \sum_{j=1}^{pi} \beta_{ij} \Delta y_{it-j} + X_{it}\delta + \varepsilon_{it}. \quad (3)$$

In Equation (3), $\alpha = p-1$ for all i but the lagged term for the difference terms p_i is allowed to vary across the cross-sections. Thus, the null and alternative hypotheses (i.e. H_0 and H_1) for the tests are:

$$\mathrm{H}_0\colon \alpha = 0, \quad \mathrm{H}_1\colon \alpha < 0. \quad (4)$$

The IPS test is based on individual roots applicable to the heterogeneous panel given as:

$$T_{\text{ips}} = \frac{\sqrt{N}(\bar{\mp} - E[t_i|p_i = 0])}{\sqrt{\text{var}}[t_i|p_i = 0]},\ N(0, 1). \quad (5)$$

N is the number of countries and $\bar{\mp} = N^{-1}\sum_{i=1}^{N} t$, which denotes the mean of the computed augmented Dickey Fuller (ADF) statistic for individual countries in the panel while p_i is the autoregressive root, $E[t_i|p_i = 0]$ and $\sqrt{\text{var}}[t_i|p_i = 0]$ are the mean and variance of the Monte Carlo simulation (AlYousef, 2011).

The Breitung (2000) test considers the common root of the series. This test does not require bias correction factors that are achieved by appropriate variable transformations and proposes a t-test statistic to examine the null hypothesis that the process is non-stationary (Narayan & Smyth, 2007). The FADF test combines the p-values of the statistic for a unit root in each cross-section (Maddala & Wu, 1999). This test combines the individual unit-root tests to derive panel-specification results.

The study assesses the long-run relationship of the selected variables using the cointegration test based on the Pedroni (1999) approach. This method uses specific parameters that are allowed to vary across the samples in order to account for possible heterogeneity in the model. The Pedroni approach has seven tests, which include panel v-statistic, panel rho-statistic, panel Phillip Perron-PP statistic, panel ADF-statistic, group rho-statistic, group PP-statistic and group ADF-statistic. The first four tests are the panel cointegration statistics built on the 'within approach', while the remaining three are the group panel cointegration statistics based on the 'between approach'. To establish the presence of cointegration amongst the variables, Pedroni noted that the residuals are expected to be stationary.

The Pedroni (1999) cointegration is not able to provide estimations for the long-run relationships existing between the variables. Kao and Chiang (2000) suggested that the PDOLS regression will provide a better estimate for the long-run relationships between the variables. The PDOLS corrects for some drawbacks common with panel data estimations such as serial correlation and endogeneity. AlYousef (2011) also observed that PDOLS uses parametric adjustment to the errors by the inclusion of past and future values of the first differenced variable. This is depicted in Equation (6):

$$y_{it} = \varphi_i + \delta X_{it} + \sum_{j=q_1}^{j=q_2} C_{ij}\Delta X_{i,t+j} + V_{it}. \quad (6)$$

C_{ij} is the coefficient of the lead and lag of the first differenced explanatory variables based on their unit-root properties. The estimated coefficients of the PDOLS imply that the 'regress' is explained by the 'regressors', the lag and lead values of the first difference of the explanatory variables ('regressors') were used as instrumental variables. Kao and Chiang (2000) and Narayan and Smyth (2007) noted that the PDOLS generates consistent estimates of the parameters in small samples and controls for the likely endogeneity of the regressors and serial correlation.

For robustness, we went further to examine if our result is sufficient in explaining the relevance of the EKC model by using other measures of pollution. This is based on the findings in extant literature, such as Taguchi (2012), that the applicability of the EKC hypothesis differs by the type of pollution applied. In this case, we made use of PM emissions. We also intended to have the inclusion of nitrous oxide and sulphur emissions as in Grossman and Krueger (1991) and Stern (2004), but data were very scanty for the sampled countries. Thus, PM was used because of data availability and due to its adverse effect on the health of the population. This kind of pollution include particles that are less than 10 μm in diameter (PM10), which are capable of penetrating deep into the respiratory tract and causing significant health damage.

5. Empirical Results and Discussion

This section begins with the discussion of the data utilized in the study, followed by the panel unit-root tests. The estimates from the panel cointegration and the PDOLS follow accordingly.

5.1. *Descriptive Analysis*

In a broader description, Table 3 presents the mean values of the variables in the model, across the 50 countries selected for the study. This was aimed at having information about the respective variables in the sampled countries. Only the mean values were reported for brevity's sake, while others such as standard deviation, minimum and maximum were not reported.

In Table 3, the average value of carbon IV oxide (CO_2) *per capita* (Clmg) for the countries (All) was 1.08, which implies that the average individual in these countries contributed about 1.08 metric tonnes of CO_2. This occurs through the burning of fossil fuel, among others. On an average, just a few countries like Algeria, Botswana, Egypt, Equatorial Guinea, Libya, Mauritania, Morocco, Namibia, Seychelles, South Africa and Tunisia had a CO_2 *per capita* value that was above the mean value for the entire sample. These countries have commonalities, especially with regards to their level of economic development and the extent of natural resource exploration. South Africa and Libya were the highest emitters, with values of 8.63 and 9.22 emissions *per capita* and Chad and Burundi had the least emission rate, with values of 0.03 and 0.04, respectively.

Observing the levels of economic development across the countries, the value of *per capita* GDP for the entire sample was 1572.34 US$. This implies that on an average, a person living in these countries will earn about 1572.34 US$ per annum. Some countries such as Equatorial Guinea, Seychelles and Libya had higher *per capita* GDP that was five times more than the average value for the entire sample. Other countries such as Burundi (130.40 US$) and Congo Democratic (132.13 US$) had a *per capita* GDP that was far below the average value of the entire sample.

With regards to the value of trade during the period, the entire sample had an average value of 77% of trade as a share to the GDP. This is without prejudice to some countries where trade had marginal contributions lower than the average value of the entire sample. In effect, countries such as Senegal, Burundi, Rwanda, Burkina Faso, Central African Republic and Ethiopia had a contribution of trade to GDP below 40%. However, others, including Mauritius, Angola, Congo Republic, Seychelles, Equatorial Guinea, Lesotho and Swaziland, had a trade to GDP contribution value of above 100%.

The institutional performance of the sampled countries, measured using the RL, RQ and GE, reveals that on an average, the sampled countries had low institutional quality. The values were -0.65, -0.67 and -0.67, respectively. As mentioned earlier, the score for the indicators of institutional quality range between -2.5 (lowest) and $+2.5$ (highest). Most of the sampled countries had negative scores. However, countries such as Botswana, Cape Verde, Namibia, Mauritius, Seychelles, South Africa and Tunisia had positive values for RL. Botswana, Mauritius, Namibia and South Africa had positive values for RQ, while Botswana, Cape Verde, Mauritius, Namibia, Seychelles, South Africa and Tunisia had positive values for GE. It can be surmised from Table 3 that on an average, countries with positive values for the indicators of institutional quality were about 10% of the sampled countries.

5.2. *Panel Unit-root Test*

The results from the four panel unit-root tests at levels and first difference are presented in Table 4. The order of the integration of the variables was also summarized in the table using the values for trend and constant.[5]

Table 4 provides reported results that the variables Clmg, Pgdp, Pgdp^2 and Trade were stationary at first difference (i.e. they follow *I* (1) process) using all the four tests. Variable Inst was stationary at levels using the LLC approach. However, using other tests, the variable was stationary at first difference. In effect, it is evident that the variables in the model follow *I (1)* process. Thus, they can be said to be compatible in the long run, even if there are short-run shocks. This will be reiterated in the next sub-section.

5.3. *Panel Cointegration Test*

The results of the panel cointegration, using the seven test statistics, are reported in Table 5. The results reveal that the H_0 of no cointegration was rejected by the PP and ADF panel and group statistics. This means that the variables can be cointegrated, thus denoting the existence of a long-run relationship between an

Table 4. Panel unit-root results

	Levin, Lin and Chu			Im, Pesaran and Shin			Breitung			ADF—Choi Z-stat		
Series	Levels	1st diff.	Order	Levels	1st diff.	Order	Levels	1st diff.	Order	Levels	1st diff.	Order
Clmg	−0.312	−10.671[a]	1(1)	1.871	−14.467[a]	1(1)	1.216	−8.985[a]	1(1)	1.721	−12.994[a]	1(1)
	(0.378)	(0.000)		(0.969)	(0.000)		(0.888)	(0.000)		(0.957)	(0.000)	
Pgdp	2.652	−5.690[a]	1(1)	8.463	−4.011[a]	1(1)	4.286	−3.860[a]	1(1)	0.155	−3.093[a]	1(1)
	(0.996)	(0.000)		(1.000)	(0.000)		(1.000)	(0.000)		(0.567)	(0.001)	
$Pgdp^2$	6.897	−5.484[a]	1(1)	9.414	−3.727[a]	1(1)	5.859	−3.078[a]	1(1)	0.382	−2.981[a]	1(1)
	(1.000)	(0.000)		(1.000)	(0.000)		(1.000)	(0.001)		(0.644)	(0.001)	
Inst	−9.026[a]	—	1(0)	−1.779[b]	−4.265[a]	1(1)	−0.471	−1.377[c]	1(1)	−1.560[c]	−4.895[a]	1(1)
	(0.000)			(0.038)	(0.000)		(0.319)	(0.084)		(0.059)	(0.000)	
Trade	−0.595	−5.548[a]	1(1)	1.645	−9.591[a]	1(1)	1.541	−0.805	1(2)	−0.418	−6.592[a]	1(1)
	(0.276)	(0.000)		(0.950)	(0.000)		(0.938)	(0.211)		(0.338)	(0.000)	

Notes: Lag lengths were chosen using the Schwartz information criterion (SIC). *P*-values are in parenthesis.
Source: Authors' computation using E-views 7.0.
[a]Denotes significance at 1%.
[b]Denotes significance at 5%.
[c]Denotes significance at 10%.

Table 5. Panel cointegration results

	Statistics	*P*-value	Weight statistics	*P*-value
Within-dimension				
Panel v-statistic	−960.8728	1.0000	−5.8964	1.0000
Panel rho-statistic	4.1640	1.0000	5.5419	1.0000
Panel PP-statistic	−10.2705	0.0000	−1.3556	0.0000
Panel ADF-statistic	−5.7603	0.0000	−0.3156	0.0000
Between-dimensions				
Group rho-statistic	6.2276	1.0000		
Group PP-statistic	−10.7560	0.0000		
Group ADF-statistic	−6.9820	0.0000		

Notes: Lag lengths were chosen using SIC, spectral estimation was carried out with Bartlett method and bandwidth was selected with Newey-West method.
Source: Authors' computation using E-views 7.0.

environmental pollution indicator and the respective explanatory variables. In other words, the variables can converge in the long run despite possible shocks in the short run.

5.4. *PDOLS Estimates*

Given that the variables in the model are cointegrated, the study further estimates the long-run relationship in order to observe the magnitude of the long-run coefficients. This is reported in Table 6.

From Table 6, the coefficient of economic development (Pgdp) was positive and significant at 5%. This finding confirms the reality of the EKC hypothesis that as the economy of a country improves, the extent of environmental pollution (CO_2 emissions) will increase. This could be explained based on the fact that in the early stage of economic development, economic structures like technology diffusion, authorities to enforce rules and regulations, which are expected to regulate the extent of environmental pollution, may not be sufficiently available. This finding supports the stance of Beckerman (1992) and Perman and Stern (2003) that at the early stages of economic development, there is bound to be environmental degradation.

The coefficient of the squared value of economic development ($Pgdp^2$) was negative and significant at 1%. Therefore, there is the existence of an inverted

Table 6. PDOLS estimates of the cointegrating coefficient

Panel DOLS (leads and lags = 1)		
Pgdp	1.5732[a]	(0.0210)
$Pgdp^2$	−0.1518[b]	(0.0010)
Inst	−0.1844	(0.1340)
Trade	−0.0041	(0.1570)

Notes: All estimations are made with random effects. Leads and lags = 1 means that first lags and leads of first differences of explanatory variables are used as instruments.
Source: Authors' computation STATA 11.1.
[a]Denotes significance at 5%.
[b]Denotes significance at 1%.

'U-shaped' trend in the relationship between environmental pollution (CO_2 emissions) and economic development. This implies that as *per capita* income increases beyond some threshold, the extent of environmental pollution will be reduced. This is as a result of the growth in the structural changes towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures. Thus, citizens will be more vigilant towards and conscious of environmental issues and hence countries will attain less environmental pollution with increasing wealth (Beckerman, 1992). This finding contradicts Galeotti *et al.* (2006) and Coondoo and Dinda (2002) who did not find evidence to support the validity of the EKC hypothesis for non-OECD countries.

The institutional quality and trade variables in Table 6 exhibit a negative relationship with environmental pollution. The estimate for institutional quality suggests that the growth in the institutional quality of the country has the potential for reducing environmental pollution. This may result from developing and enforcing institutional checks on economic agents' interactions with the environment. However, this implication is not statistically significant. This can be explained by the fact that institutional quality in most African countries is not resilient enough to induce the needed environmental controls that will 'tailor' the behaviours of economic agents towards caring for the environment.

The coefficient for trade variable is negative but insignificant at 5%. This implies that increase in trade does not significantly contribute to environmental pollution in Africa.[6] This contradicts the submission of Halicioglu (2009) but can be explained based on the fact that most international trade activities involve the use of sea transport compared to air transport which has been directly traceable to be a considerable contributor to global CO_2 emissions. Furthermore, African countries are net importers and imported goods do not contribute to the production processes in the country and thus produce minimal waste.

5.5. *Robustness Checks*

Having tested the unit-root property of particulate matter (PM10) and having ascertained that it is stationary at the first difference (see Table A1 in the appendix), a likely long-run relationship exists between PM10 and the other explanatory variables. Other explanatory variables were all stationary at first difference. We further examined the long-run relationship using the same approach as the CO_2 model and the result is reported in Table 7.

The table reveals that in the long run, the relationship between income and environmental pollution, based on PM10, follows an inverted 'U shape'. This is similar to the earlier result when using CO_2. Trade and institution were still not significant in the long run, though they had expected signs. However, we compared the magnitude and we observed that the effect of economic growth is higher for PM10 than CO_2. Explicitly, during early growth of the economy, additional income will result in a higher proportionate change in PM10 (8.3621) than in CO_2 (1.5732). Similarly, as income increases, PM10 reduces proportionately (1.3931) compared to CO_2 (0.1518). The implication of this result is that in policy stance, other toxic gaseous pollutions should be considered as their reaction to policy stance may be more significant than CO_2. This is based on the fact that CO_2 may not be easily controlled, especially in developing countries like Africa, because major economic activities such as industry/manufacturing and transpor-

Table 7. PDOLS estimates of the co-integrating coefficient (using PM10 as dependent)

Panel DOLS (leads and lags = 1)		
Pgdp	8.3621[a]	(0.0150)
$Pgdp^2$	−1.3931[b]	(0.0000)
Inst	−1.9118	(0.8360)
Trade	0.0067	(0.876)

Notes: All estimations are made with random effects. Leads and lags = 1 means that first lags and leads of first differences of explanatory variables were used as instruments.
Source: Authors' computation STATA 11.1.
[a]Denotes significance at 5%.
[b]Denotes significance at 1%.

tation emit this kind of pollution. Similarly, institutions are not as developed to enforce regulations to reduce the emission of CO_2.

Finally, we estimated the long-run equation based on the categorization of our selected countries into oil[7] and non-oil producers. The outcome of this estimation is reported in Table 8. From the table, we observe that the EKC hypothesis applies significantly for oil-producing countries. In the non-oil-producing countries, it can be noticed that the signs hold for both *per capita* GDP and its square, but the levels of significance were not validated.

From the foregoing discussions, we can surmise that for policy actions the developmental policies that will improve the general income of the society should be driven for mitigation of environmental pollution. This is based on the fact that the EKC hypothesis holds for African countries and as economic growth improves, environmental pollution begins to fall. However, we caution that this does not occur in isolation as strengthening the institutions to drive environmental pollution will be required. In essence, the argument of EKC being valid or not should not fundamentally be the concern for policy-makers; rather the concern should be how the productive process of firms and those of behavioural patterns of citizens can be curtailed in the interest of the environment. This will call for the collaboration of both the regulative and normative institutional structure to formulate and adhere to core environmental policies such as decent and resourceful waste disposal and management systems.

Table 8. PDOLS estimates of the co-integrating coefficient based on oil-producing countries (using CO_2 as dependent)

Panel DOLS (leads and lags = 1)	Oil-producing	Non-oil-producing
Pgdp	2.0960[a] (0.0570)	0.8942 (0.3210)
$Pgdp^2$	−0.1366[b] (0.0380)	−0.1099 (0.1110)
Inst	0.3796 (0.2010)	−0.2595 (0.1750)
Trade	0.0094[c] (0.0050)	−0.0077[c] (0.0010)

Notes: All estimations are made with random effects. Leads and lags = 1 means that first lags and leads of first differences of explanatory variables are used as instruments.
Source: Authors' computation STATA 11.1.
[a]Significance at 10%.
[b]Significance at 5%.
[c]Significance at 1%.

6. Conclusion

The EKC hypothesis, which posits the existence of an inverted U-shaped curve between environmental pollution and economic development, has been the subject of wide ranging debates, particularly in developed countries, despite evidence of its applicability to these contexts. Some scholars support the maxim, while others hold a contrary view. This study contributes by providing an empirical investigation on the extension of the EKC in explaining the relationship between environmental pollution and economic development in Africa. The extension made includes the use of panel cointegration to address some of the econometric concerns, focusing mainly on African countries and thus addressing the issue of regional differences; and the inclusion of institutional quality and trade as additional control variables. Some of the main findings are summarized herein.

The study established that a long-run relationship exists between the indicator of environmental pollution (CO_2 emissions and PM emissions), *per capita* income and its square, institutional variable and trade, thus denoting the possibility of the chosen explanatory variables converging with environmental pollution in the long run. This implies that jointly institutional quality, trade and economic development can explain the extent of environmental pollution parameters in the long run. The long-run estimates validate the reality of the EKC hypothesis in Africa as *per capita* income and its square were significant with expected signs, in tandem with the EKC hypothesis. This implies that in the long run, the economic development process in Africa matters to the extent of environmental pollution, which suggests the need for African countries to reduce the level of environmental pollution at higher levels of economic development.

To spur economic growth while minimizing environmental pollution there is need for strong institutions to enact effective policy and rules and regulation that will support sustainable development. Therefore, Africa has opportunity and it can *tunnel* the EKC trajectory and avoid what may become irreversible environmental damage, since most of these countries are still at relatively low levels of development. In summary, the immediate concern for policy-makers should be the mechanisms to influence the productive process of firms and that of citizens in the quest for being more environmentally conscious. An agglomeration of efforts is also suggested. This will involve a situation where the government through its agency will stipulate mechanisms (e.g. environmental laws and the means of enforcement) and the readiness to adhere by other economic agents (e.g. firms seeing it as corporate social responsibility and households taking it as civic responsibility).

It can be recommended that more frantic efforts in mitigating the causes of environmental pollution are imperative by enhancing the development process through environmental-friendly techniques of production. In this line of thought, conservation activities like planting of trees to reduce the effect of desertification and balancing of the ecosystem in African countries are essential. Some advocacies have already been kicked off in few countries like Kenya; the stepping up of the process through institutional quality that involves the enactment and enforcement of enabling law is recommended. The issue of waste management in terms of better means of disposal and recycling that will require law and enforcement and general economic development is also essential. In sum, the paper submits that the argument of EKC being valid or invalid should not be the primary issue for African countries but how production and consumption (firms and households) can be carried out in the interest of the environment. This is especially true for the oil-producing countries that are among those with the highest level of GDP *per capita*.

Acknowledgements

We acknowledge the useful comments from the organizers and participants at the International Conference on Public Policy Governance (2012), Indian Institute of Science, Bangalore, India, 4–6 September 2012, where the first draft was presented. Useful comments from the anonymous reviewers are also appreciated.

Notes

1. In panel data analysis, both the individual observations (e.g. countries) and time dimension (e.g. year) are included. It is basically employed to improve the degrees of freedom as the number of observations is greatly increased.
2. There could be the possibility that the strength of the institutions in a country is determined by her level of economic development, which can also be influenced by the extent of economic activities, suggesting the problem of endogeneity. However, with the use of thePDOLS technique, such a challenge can be addressed (Kao & Chiang, 2000; Narayan & Smyth, 2007).
3. Effort was made to include energy usage in the model. However, most of energy usage indicators such as electricity production and consumption were not available for most of the sampled countries for the period.
4. Though there could be the possibility of export and import having different impacts on the environment, the emphasis here is to evaluate the general impact of trade. The segregated impact is being examined elsewhere.
5. The study examined the results with/without trends; not much difference was observed. Hence, only results with trend were reported.
6. This is interpreted with some caution as other trade indicators such as real growth in trade were not available for comparison.
7. The list of oil producers in Africa include Algeria, Angola, Cameroon, Congo Democratic Republic, Egypt, Congo Republic, Cote d'Ivoire, Equatorial Guinea, Gabon, Ghana, Libya, Mauritania, Morocco, Nigeria, Sierra Leone, South Africa, Sudan, Tunisia and Zambia.

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Appendix 1

Table A1. Panel unit-root results

	Levin, Lin and Chu			Im, Pesaran and Shin			Breitung			ADF—Choi *Z*-stat		
Series	Levels	1st diff.	Order	Levels	1st diff.	Order	Levels	1st diff.	Order	Levels	1st diff.	Order
PM10	−1.089 (0.138)	−17.447 (0.000)	1(1)	−1.252 (0.968)	−17.836 (0.000)	1(1)	−1.578 (0.057)	−6.481 (0.000)	1(1)	2.271 (0.998)	−15.383 (0.000)	1(1)