Economic growth and environmental pollution: an estimation of the Environmental Kuznets Curve for 14 countries in Sub-Saharan Africa

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ABSTRACT: The objective of this article is therefore to analyze the link between economic growth and environmental degradation in the case of 14 countries of sub-Saharan Africa. From WDI data over the period from 1970 to 2018, we estimated the Environmental Kuznets curve (CKE) in panel by the within estimator, based on the one-way fixed effect method. The results indicate that the CKE is not validated, but that there is a linear and positive relationship between economic growth and pollution. As a measure of robustness, we proceed to another estimation of our model using the Two-Way fixed effects method. The results confirm once again the non-validation of the Environmental Kuznets Curve (EKC) for our panel, and confirm the existence of a linear and positive relationship between economic growth and pollution. We have announced to these countries to set up public policies aimed at industrialization and environmental protection.

KEYWORDS: Fossil energy consumption; Economic growth; Pollution; Environmental Kuznets Curve

Introduction

Energy consumption plays a very important role in the relationship between economic growth and the environment. Indeed, the production and consumption of fossil fuels, with their positive influences on economic growth, has harmful effects on the environment because of the pollution they generate. In this sense, Forster (1973), followed by Luptacik & Shubert (1982), Van Der Ploeg & Withagen (1991), think that one cannot speak of energy consumption and economic growth without integrating environmental questions.

From the point of view of economic theory, the analysis of the relation which links economic growth to the environment finds its foundation in the works of Grossman and Krueger (1994) which dwelled heavily on the curve of Environmental Kuznets (CKE). Indeed, it is a curve in the shape of a bell or an inverted "U" which connects economic growth on the x-axis and the degradation of the environment on the y-axis.

Empirical verification of CKE, or in other words the existence of an inverted “U” relationship between growth and pollution has been tested in the case of the USA by Grossman and Krueger (1994) and confirmed by Millimet et al. (2000) for the same country. However, for the same country, the analysis of Arrow et al (1995) and Dinda (2004) have brought enormous criticism of CKE; the criticism of the first concerns the existence of a feedback effect between growth and pollution1 and that of the second on the shape of the curve2.

1For Arrow (1995), it is pollution that acts on economic growth unlike CKE.
2Dinda (2004) show that the inverted "U" shape of CKE is not the only one, since there are other shapes ("N and reverse N", "U", "positive or negative linear").
Building on these divergences in work, our objective in this article is to analyze the relationship between economic growth and pollution in sub-Saharan Africa with a view to identifying priority with regard to the two main concerns faced by developing countries in general, and those of Sub-Saharan Africa in particular, namely a high level of economic growth and environmental protection.

The question to ask is what is the effect of economic growth on the environment for 14 countries in Sub-Saharan Africa? More specifically, what is the link between economic growth and pollution for 14 countries in Sub-Saharan Africa? More simply, what is the shape of the environmental Kuznets curve (CKE) for 14 countries in Sub-Saharan Africa? To address this problem, the article presents: the literature review, the methodology, the empirical results and the recommendations.

1. Literature review: the theoretical and empirical link between growth and pollution

The EKC hypothesis has been debated for at least 25 years (Stern, 2017). Indeed, the review of the literature on the existing relationship between growth and pollution is based on the theory of the environmental Kuznets curve (CKE) developed by Grossman and Krueger (1994). Here we will offer a review of theories and empirical work on the issue.

1.1 Review of theories: theoretical explanation of CKE and its main economic implications.

1.1.1 Theoretical explanations of the CKE.

The environmental Kuznets curve (CKE) developed by Grossman and Krueger (1994) is the adaptation in the environment sector of the Kuznets curve describing the relationship between per capita income and income inequality.

Researchers have found that in the early stage of economic development, environmental pollution would increase with the increase of per capita income; however, when income reached a certain level, environmental pollution would fall with the increase of per capita income (Grossman & Krueger, 1995; Sarkodie & Strezov, 2019; Su & Chen, 2018).

Graph 1: Environmental Kuznets curve on the relationship between growth and pollution.

This curve has 3 bands; the first band is that of the pre-industrial economies which seek to organize themselves out of poverty. In this context, they therefore use natural resources and above all energy which have a harmful effect on the environment. At this level, there is a

3 By estimating for this zone the Kuznets Environmental curve (CKE).
positive and growing relationship between the increase in growth and the increase in emissions of pollutants that degrade nature. After this stage, our economies move from a primary level to that of an industrialized country. This stage, known as a transition stage, is characterized by an increase in the use of energy resources accelerating environmental pollution which reaches its peak at the top of the inverted "U" curve. But as wealth is already obtained, the turning point or transition takes place, since at this level, our industrialized economies are looking for a healthy environment and are implementing a transition process towards technologies using green energies which are less polluting by their activity. The last band is that of post-industrial economies that engage in pollution control activities, since at this level, there is a linear and negative relationship between the evolution of wealth and environmental pollution.

1.1.2 Economic implications of CKE: some controversial analysis.

From the point of view of economic literature, the main form of EKC is based on the fact that when an economy reaches a significant level of development, it is devoted to environmental activities (Pezzey, 1989; Selden & Song, 1994; Baldwin, 1995); in this sense it is therefore growth that acts on the environment. Indeed, for Roca (2003), the populations which have reached a high and significant per capita income, are inhabited by the desire to create a quality environment, by participating in programs and activities for nature conservation (integration and donations in NGOs specialized in the field, and the consumption of increasingly organic soil products). For Le Blanc (2015), economic growth has negative environmental externalities.

It is the accumulation of production inputs that would be the source of good economic growth (Lopez (1994)), but on the other hand, even if companies with the aim of increasing production use products pollutants, populations for example will increasingly want to pay for a healthy environment.

These are international transactions based on the theory of comparative advantages, which would verify the EKC (Arrow et al. (1995) and Stern et al. (1996)). According to this theory, each country that exchanges is supposed to specialize in the production of goods and services for which the factors are sufficiently abundant. In this context, the EKC is justified since the developed countries intensify the production with physical capital factors (machines) and human (trained labor), while the developing countries specialize in the production of goods whose natural resources and unskilled labor are the main factors. The reduction in pollutant emissions in industrialized countries is believed to be due to the transfer of certain CO\textsubscript{2}-emitting activities to developing countries. Indeed, international trade has an effect on the relationship between pollution and growth to the extent that, through the solution haven hypothesis, multinationals on the basis of their relationship with the outside, settle in these countries and pollute their environment (see Copeland and Taylor, 2003; Eskeland and Harrison, 2003; He, 2006). Thus, an increase in international trade has a positive effect on the quality of the environment of rich countries, but harmful on that of poor countries (Copeland and Taylor, 2004).

For Panayotou (1993), Stern (2004), it is industrialization that has a negative effect on the environment, since industrial production is energy intensive. Similarly, outside of GDP, the share of industry in the economy (% of GDP) can be used to influence the direction of the relationship between GDP and pollution. Furthermore, urbanization can also have an effect on the degradation of nature (Martinez-Zarzoso and Maruotti, 2011; Wang et al., 2011). Since the effect of population growth on the quality of the environment (emission of CO\textsubscript{2} and SO\textsubscript{2}) have been highlighted by Cole and Neumayer (2004).
However, the controversy over CKE based on the feedback\textsuperscript{4} effect is formulated by Arrow et al. (1995). Indeed, in "The World Development Report (1992)", the rejection of the non-feedback hypothesis on CKE, supposes the influence of the quality of the environment on GDP. According to this hypothesis, the improvement of the living conditions of the populations based on energy resources is proven and beneficial for them, however the harmful and negative impacts on nature are also proven. Therefore, if it is affirmed that it is growth which acts on the environment, we can also be led to ask the question of knowing if it is not the quality of the environment which acts on GDP in turn. Thus, for Lieb (2003), if per capita income affects the quality of the environment, this too in turn would have an effect on per capita income. In another idea, the impact of the quality of the environment on per capita income is possible insofar as the introduction of a certain level of pollutants or pollution, can cause workers to reduce productivity of work, due to health, concentration and learning problems (Van Ewijk & Van Wijnbergen, 1995). Conversely, in a recent study on the impact of pollution on working hours of residents of an oil refinery, Hanna and Oliva (2015) concluded that a 20% decrease in sulfur dioxide causes a 1.3 hour increase in working hours.

1.2 Theoretical model and empirical work on CKE

We will present here the theoretical model from which we can propose an estimate of the Kuznets curve, as well as the various empirical works obtained on the question.

1.2.1 Theoretical model on CKE.

The opinions observed in the review of the literature on the theory of EKC, gave several reflections not only on the direction of the relationship between pollution and the environment, but also on the shape of the Kuznets curve. Thus in certain works, the existence of a curve in the shape of an inverted "U" is proven, while for others, several other forms have been worked out. Therefore, from a general point of view, the EKC hypothesis as tested empirically by Grossman and Krueger (1991), is based on the following equation (1) to be estimated:

\[
Y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 Z_{it} + \epsilon_{it} \quad (1)
\]

The majority of empirical studies to verify the relationship between growth and pollution have been done using reduced, cubic or quadratic models as defined above (Dinda, 2004). With \( y \) the variable representing the environment, \( x \) the matrix of the variables of income per capita, \( z \) all other control variables apart from income that can explain the environment. \( \alpha_i \) is the constant term of the model of country \( i \), \( t \) time, and \( \beta_k \) the different coefficients of the \( k \) explanatory variables (with \( k = 1,2,3, \)), the sign of which gives meaning to a potential form of the EKC. In this context, 7 different forms can be defined according to the signs of the coefficients \( \beta_k \).

1- If \( \beta_1 = \beta_2 = \beta_3 = 0 \), then there is no relationship between the income variable \( x \) and the environment-related variable \( y \).

2- If \( \beta_1 > 0 \) and \( \beta_2 = \beta_3 = 0 \), then there is a positive linear relationship between income \( x \) and pollution \( y \).

3- If \( \beta_1 < 0 \) and \( \beta_2 = \beta_3 = 0 \), then there exists between income \( x \) and pollution \( y \) a negative linear relationship.

4- If \( \beta_1 > 0; \beta_2 < 0 \) and \( \beta_3 = 0 \), then the form of the relationship between income \( x \) and pollution \( y \) is in inverse “U” In this case, the EKC hypothesis is verified.

\textsuperscript{4}Still called a feedback effect, the author shows that unlike CKE, it is the quality of the environment that causes growth.
If $\beta_1 < 0 \land \beta_2 > 0 \land \beta_3 = 0$, then the relation is in the form of “U” between the income $x$ and the pollution $y$.

If $\beta_1 > 0 \land \beta_2 < 0 \land \beta_3 > 0$, then the relation between the income $x$ and the pollution $y$ has a polynomial cubic form or in the form of “N”.

If $\beta_1 < 0 \land \beta_2 > 0 \land \beta_3 < 0$, then the relation takes the form of an inverse “N”. The EKC hypothesis corresponds to case 4 in which $\beta_1 > 0 \land \beta_2 < 0 \land \beta_3 = 0$.

The table below therefore represents the different forms that EKC can take:

### Table 1: Different forms of the growth-environment relationship.

<table>
<thead>
<tr>
<th>Positive linear relationship</th>
<th>Negative linear relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>If $\beta_1 &gt; 0 \land \beta_2 = \beta_3 = 0$</td>
<td>If and only if $\beta_1 &lt; 0 \land \beta_2 = \beta_3 = 0$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relation in the form of &quot;U&quot;</th>
<th>Relation in the form of &quot;Inverted U&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>If $\beta_1 &lt; 0 ; \beta_2 &gt; 0 \land \beta_3 = 0$</td>
<td>If $\beta_1 &gt; 0 ; \beta_2 &lt; 0 \land \beta_3 = 0$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relation in the form of &quot;Inverted N&quot;</th>
<th>Relation in the form of &quot;N&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>If $\beta_1 &lt; 0 ; \beta_2 &gt; 0 \land \beta_3 &lt; 0$</td>
<td>If $\beta_1 &gt; 0 ; \beta_2 &lt; 0 \land \beta_3 &gt; 0$,</td>
</tr>
</tbody>
</table>

### 1.2.2. Some empirical results on EKC

The first explicit mentions linked to empirical work on the link between growth and pollution were implemented in 1970 by the economists of the Club of Rome who assume the significant impact that the intensity of use of natural resources can have on the growth. Thus over time, it is empirically shown that the use of natural resources and income describe an inverted "U" shaped relationship called "intensity-of-use hypothesis" (Auty, 1985).

However, it is Grossman and Krueger who deserve credit for having tested the EKC for the first time. In a panel, they are testing the environmental impacts of the North American Free Trade Agreement (NAFTA). With sulfur dioxide (SO$_2$) as an environmental variable, it checks the EKC, and the turning points are between $4,000 and $5,000.

For a dozen indicators, Shafik and Bandyopadhyay (1992) wanted to test the EKC, and it is only the environmental pollutants in the air variable which describes a relationship in the form of an inverted "U" with income, with turning points between $3,000 and $4,000, and the other indicators describe a neutral (deforestation), linear and positive (quality of rivers), and negative linear (lack of drinking water and sanitation) relationships. However, the results are ambiguous in the case of carbon dioxide (CO$_2$) emissions.

Using four variables, sulfur dioxide (SO$_2$), nitrate monoxide (NOx) and airborne particles (SPM), Selden & Song (1994) tried to test the EKC. They conclude that the EKC is satisfied for all environmental variables, but the turning points vary depending on the pollutants.

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5These forms also integrate case 1 which represents neutrality.
Indeed, the level of income from which pollution reaches its maximum is $8,700 for SO$_2$, $11,200 for NOx, 10,300 for SPM and finally $5,600 for carbon dioxide (CO$_2$).

For List & Gallet (1999), over the period from 1929 to 1994 in the case of the United States, it has been shown that there is an inverted U-shaped relationship between growth and pollution for sulfur dioxide (SO$_2$) and nitrate monoxide (NOx) per capita. These results have been found identically by Cole (2000b), Hill & Magnani (2000), Millimet et al. (2000). However, the nuance comes from Cole et al. (1997) who analyzed this relationship between several environmental elements (PMS, SO$_2$, NO$_2$, methane emissions, etc.) and came to the conclusion that the EKC is satisfied only for certain pollutants. It appears from these results that the environmental variable for which the EKC is not always satisfied is CO$_2$, and to another extent, if this hypothesis is satisfied, the turning points are very high and sometimes nonexistent.

Moreover, a growing body of evidence points to the likely existence of an N-shaped relationship between economic development and environmental pollution (Galeotti et al., 2006; Kang et al., 2016; Kijima, Nishide, & Ohyama, 2010; Pandit & Paudel, 2016; Sarkodie & Strezov, 2019; Sinha & Bhattacharya, 2017).

The work of Shafik (1994), in the context of 149 countries over the period from 1960 to 1990, assumes a positive relationship between CO$_2$ and GDP, despite the absence of a turning point, unlike the work of Holtz-Eakin & Selden (1995) from a panel of 131 countries between 1951 and 1986, for which the EKC is satisfied, with a very high turning point of $35,428. Recall that the EKC is not always verified on heterogeneous data, but is almost always verified for uniform and homogeneous countries; this is the case for structurally close OECD countries where the EKC is satisfied (Dijkgraaf & Vollebergh, 1998; Selden & Song, 1994; Cole et al. 1997). Likewise, countries with higher income gaps between economies give a high turning point, as opposed to countries with small income gaps. List and Gallet (1999), Stern & Common (2001).

However, Hill & Magnani (2002) show that the EKC is satisfied for a panel of 156 countries. However, when making estimates by group of countries of high, middle and low income, the EKC is not satisfied. In order to obtain the most often significant results, several studies have introduced additional variables called “control variables”, either political (Torras & Boyce, 1998), commercial (Panayotou, 1997) or energetic (Jobert & Karanfil, 2010).

2. Methodology and presentation of the EKC estimation results

At this level we will define the variables of the model, present the database and the econometric model to be estimated, without forgetting to present the estimation results of the EKC.

2.1. Methodological analysis: data, variables and analysis model

This section is devoted to the presentation of the methodological analysis. We will therefore present the data, the variables and the analysis model.

2.1.1. Data and variables of the model

The data that we are going to use comes from WDI 2019 data (World Development Indicator) from the World Bank during these various surveys for the economic or macro-econometric analysis that it performs in the world. They span the period from 1970 to 2018, and concern 14 countries in the sub-Saharan Africa zone, namely South Africa, Cameroon, the Republic of the Congo, Cote d’Ivoire, Ethiopia, Gabon, Mozambique, Nigeria, Senegal, Sudan, Tanzania, Togo, Zambia and Zimbabwe.

The choice of these countries is being made on the basis of available data. In accordance with the literature, we will use the variable "GDP" per capita (constant in 2010 dollars) to capture
growth, and energy through energy consumption "EC" and energy production from non-renewable resources "Epnrr" (in kilotonnes of oil equivalent KTEP and KWH) respectively. The gas emission will be captured by the CO₂ emissions per capita in metric tons "Eco2it", and the demographic growth is captured by the density of the population "Denspopit" (compared to the number of people per km²) and the rate of economic growth (as a percentage of GDP it) is noted “g”. Let us recall that Gdp and the emission of co2 constitute our main variables, while the control variables having been added and which can influence these relations from the point of view of the literature are energy consumption, energy production, density of population and the rate of economic growth.

2.1.2. The analysis model

According to the specification of Grossman and Krueger obtained from equation (1), we can retain the linear, quadratic and cubic forms (Kaika & Zervas, 2013; Wang et al., 2017), then estimate in the case of 14 countries of sub-Saharan Africa, the model:

\[ \text{Eco2}_{it} = \alpha_i + \beta_1 \text{Gdp}_{it} + \beta_2 \text{Gdp}_{it}^2 + \beta_3 \text{Gdp}_{it}^3 + \beta_4 \text{Ec}_{it} + \beta_5 \text{Epnrr}_{it} + \beta_6 \text{g}_{it} + \beta_7 \text{Denspop}_{it} + \epsilon_{it} \]  

(2)

The constant term \( \alpha_i \) represents the unobserved specific effects of countries \( i \) and \( \epsilon_{it} \) the residual over time for each country \( i \). the \( \beta_i \) represent the slope of coefficients to be estimated.

\( i = 1, \ldots, 7 \) and \( t = 1, \ldots, T \) denotes the evolution of each variable over time for country \( i \).

2.2. EKC estimation, results and discussion

The Fisher test is carried out in order to check the homogeneity of our panel, and that of Hausman in order to select the best estimator.

2.2.1. Pre-estimation tests and results: The Fisher and Hausman test

The estimation of the model (2) in a panel requires prior verification of the homogeneity of the individuals in the sample and that of Hausman's individual specificity. Indeed, for the first test, before estimating our model, it is important to check if the individuals have individual characteristics which are their own. In this context, remember that our estimate relates to a panel of 14 countries in sub-Saharan Africa, most of which do not belong to the same geographic, economic and even monetary area. It is therefore important to carry out the Fisher test which makes it possible to test the null hypothesis of homogeneity of the sample \( H_0 (\alpha = \alpha_i; \beta = \beta_i) \) against the alternative hypothesis of heterogeneity \( H_1 (\alpha \neq \alpha_i; \beta \neq \beta_i) \).

The application on software whose results are contained in appendices (1) rejects the hypothesis of homogeneity of the sample since the value of F (13, 622) = 124.9, and the probability (p-value) is less than 5%. In this context, according to theory, the estimation of such a model by OLS would give us biased results.

Hausman's (1978) test thus aims to select the estimator that will end up giving us better results since it is econometrically appropriate to use either the Within (intra-individual) estimator if the effects are fixed, or the GCM estimator (interindividual) if the effects are random. We test the hypotheses \( H_0 E(\beta/X_i) = 0 \) (the MCG estimator of the random effect model is effective) against \( H_1 E(\beta/X_i) \neq 0 \) (the MCG estimator of the random effect model is biased by where the choice of the Within estimator). The results of the Hausman test based on the chi-square statistics are contained in appendix 2. They show that we cannot reject hypothesis \( H_1 \) since the chi-square with 5 degrees of freedom (51.54) has a p-value of 0.000 (significant at 1%, 5%, and 10%). We therefore use the Within estimator to interpret our results.

The following table gives the results of estimating equation (2) by the Within estimator.

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6Outside the African continent.
Table 2: Results of panel EKC estimates by the one fixed effect method m (Eco$_2$, is endogenous variable).

<table>
<thead>
<tr>
<th>Exogenous variable</th>
<th>Fixed effects</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_i$</td>
<td>0.7648325***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Gdp</td>
<td>-0.0004546***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Gdp$^2$</td>
<td>0.000...0012***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Gdp$^3$</td>
<td>-0.000...00416***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Ce</td>
<td>0.0008476***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Pernr</td>
<td>0.0018314</td>
<td>(0.164)</td>
</tr>
<tr>
<td>$g$</td>
<td>-0.0018384</td>
<td>(0.590)</td>
</tr>
<tr>
<td>Denspop</td>
<td>0.0033692*</td>
<td>(0.08)</td>
</tr>
</tbody>
</table>

$R^2$ corrigé 0.4240

F 124.9*** (0.000)

PR Nd

(***) (**) (*) significance of the coefficients at the 1%, 5% and 10% threshold. PR: turning point, Nd: not defined.

Source author on stata 13.

The results of the estimates show that the inverted U-shaped relationship is not obtained, since we have the coefficients $\beta_1<0$, $\beta_2>0$ and $\beta_3<0$. We therefore conclude that the EKC is not satisfied in the case of 14 countries in Sub-Saharan Africa, an acceptable result for developing countries. However, even if the EKC is not satisfied, there is still an inverted "N" shape like Bellla, Gianni, Carla Massidda & Ivan Etzo (2010) in the case of 55 non-OECD countries. Similarly, according to the literature, there is a positive relationship between growth and pollution for the 14 countries of sub-Saharan Africa, as in Shafik (1994), Moomaw & Unruh (1997).

The influence of the control variables as recommended in the literature is to be analyzed; indeed, energy consumption positively influences the emission of CO$_2$ as in Jobert et al. (2011). The production of energy from non-renewable resources, and the rate of economic growth have no influence on the emission of CO$_2$. Population density has a negative effect on CO$_2$ emissions, showing that high population growth translates into lower CO$_2$ emissions, results which corroborate with results of Nguyen (1999), Selden & Song (1994), Cropper & Griffiths (1994) and Panayotou (1997).

The calculation of the turning points for the panel of 14 countries in sub-Saharan Africa, should give us two turning points, one minimum and the other maximum of the inverted N form. However, since the values of the slope coefficients are very low for $\beta_2$ and $\beta_3$ relative to that of $\beta_1$, it is therefore impossible to calculate turning points whose shape is indeterminate.

Indeed, the non-determination of the turning point is very important in the analysis of the relationship between growth and pollution. These points designate the income threshold from which a developing country can already consider itself industrialized, in order to indulge unconditionally in activities of environmental protection, through the reduction of production and consumption in fossil fuels (Roca, 2003). It emerges that the non-determination of these turning points is the main limitation of this work. However, in the case of African countries, this point is almost never obtained, since the EKC is only valid for groups of industrialized

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7 Within estimator.

8 Calculated by formula $x^* = \exp\left[(-\beta_1 \mp \sqrt{\beta_1^2 - 3\beta_2\beta_3})/3\beta_1\right]$. 

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countries with homogeneous economies (Dijkstra & Vollebergh, 1998; Selden & Song, 1994; Cole et al., 1997).

2.2.2. Discussion of main results

The results obtained by the one-way fixed effect method through the within estimator show that the EKC is not satisfied in the case of 14 countries of Sub-Saharan Africa, a result acceptable for developing countries. Indeed, the validation of the Environmental Kuznets curve is done by developed countries which have already reached a certain level of development, and decide to devote their wealth to the benefit of nature and environmental protection activities (Roca, 2003). However, even if the EKC is not satisfied, we still find an inverted "N" shape like Bellla, Gianni, Carla Massidda & Ivan Etzo (2010).

The Kuznets curve with an inverted "N" shape assumes that the course between economic growth and pollution is very unstable. Indeed, the first phase of the curve shows that economic growth and pollution decrease inversely, then increase in the same direction in a second phase, in order to evolve in the opposite direction in the third and final phase. At the same time, another interpretation of the "N" shape assumes that when economic development captured by income per capita increases, pollution decreases, increases in the second phase, and finally decreases in the last phase. Thus, initially, pollution decreases as income per capita increases. However, along with this economic development, new types of pollution will appear, these new types of pollution may not be effectively reduced by existing environmental technologies and regulations (Yuan, Yin, Soleil, & Chen, 2019). Panayatou (1997) therefore suggests basing economic development on strict environmental policies. Therefore, when the government collects enough information on pollution and uses cleaner technologies to produce goods, the government will be able to set higher environmental standards and pass more environmental regulations (Dutt, 2009; Yin et al., 2015; Sinha & Bhattacharya, 2017).

These previous analyzes go hand in hand with the existence of a linear and positive relationship between economic growth and pollution for these 14 countries. The influence of the control variables on the level of pollution seems to corroborate with the analyses identified in the literature. As in Jobert et al. (2011), fossil fuel consumption influences pollution, while energy production from non-renewable resources has no influence on CO2 emissions. Population density has a positive effect on CO2 emissions, showing that population size plays a significant role in increasing pollution.

By way of discussion, we will validate the quality of our results by another static panel estimation technique. Indeed, as opposed to the one-way fixed effect method, we will proceed to the robustness of our results by the two-way fixed effect method. The application of Fisher test rejects the null hypothesis of homogeneity of the individual dimension and validates this method.

\[ F(13, 578) = 124.59, \text{Prob} > F = 0.0000 \]
Table 3: Results of panel EKC estimates by the Two-way fixed effect method (Eco₂, is endogenous variable).

<table>
<thead>
<tr>
<th>Exogenous variable</th>
<th>Two-way Fixed effects¹⁰</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>αᵢ</td>
<td>4.6346***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Gdp</td>
<td>-0.000364***</td>
<td>(0.003)</td>
</tr>
<tr>
<td>Gdp²</td>
<td>0.000…0012***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Gdp³</td>
<td>-0.000…00407***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Ce</td>
<td>0.00103***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Pernr</td>
<td>0.0007846</td>
<td>(0.546)</td>
</tr>
<tr>
<td>g</td>
<td>-0.002826</td>
<td>(0.416)</td>
</tr>
<tr>
<td>Denspop</td>
<td>0.1074***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>R² corrigé</td>
<td>0.9654</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>248.18***</td>
<td>(0.000)</td>
</tr>
<tr>
<td>PR</td>
<td>Nd</td>
<td></td>
</tr>
</tbody>
</table>

¹⁰ Within estimator.

(***), (**) (*) significance of the coefficients at the 1%, 5% and 10% threshold. PR: turning point, Nd: not defined.

Source: author.

The results obtained by the two-way fixed effect method validate and confirm those obtained by the one-way fixed effects. In fact, these results validate the existence of an inverted “N” relationship between the economic growths captured by the Gdp per capita and level of pollution. Likewise, the existence of a linear and increasing relationship between these variables is validated. In addition, the influence of control variables as we have the same effect on pollution. This new estimate confirms and strengthens the quality of our previous analyzes, the purpose of which is to obtain good recommendations for economic and environmental policy.

**Conclusion**

Africa in general and the sub-Saharan part in particular faces constraints that seem to be imposed on it by international institutions and industrialized countries in the Paris agreements (2015), namely limiting the production and use of fossil fuels, formulate economic policies, one of the axes of which is the protection of the environment and the reduction of co₂ emissions. However, these are the countries that are not responsible for the current pollution, and have the natural and energy resources that could allow them to develop. One of the avenues that can provide solutions to this constraint is based on the analysis of the Environmental Kuznets Curve (EKC), the validation of which would lead to an economic policy recommendation consisting in turning to clean or green growth.

The objective of this article was to analyze the relationship between economic growth and pollution for 14 countries in Sub-Saharan Africa. From the within estimator based on one-way fixed effect model, we proceeded to estimate the Environmental Kuznets curve (CKE) for the panel over the period from 1970 to 2018. The results show that the EKC hypothesis is not validated for these 14 countries. Indeed, the non-validation of this hypothesis indicates that African countries are not already prepared for the energy transition. However, these analyzes validate the existence of a linear and positive relationship between economic growth and pollution. Showing that any increase in the level of wealth would lead to an increase in the level of pollution. The Two-way fixed effect model method is used as a robustness, validating all the existing relationships between pollution and economic growth. Notably the existence
of an inverted "N" shaped relationship, and finally the existence of a linear and positive relationship between them. Finally, the effect of the control variables on the level of pollution is also confirmed by this method. So like Beckerman (1992), one might think that the only way for developing countries to protect the environment is to get rich. We recommend to these countries the establishment of public policies focused on industrialization and environmental protection.

References


• Su, E. C., & Chen, Y. (2018). Policy or income to affect the generation of medical wastes: An application of environmental Kuznets curve by using Taiwan as an example. *Journal of Cleaner Production*, 188, 489–496.


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**Annexes**

Annex 1: Results of the homogeneity test of individuals from the one-way fixed effect method

```
.xtreg ECo2 pib pib2 pib3 ce pernr g denspop, fe

Fixed-effects (within) regression                       Number of obs  =  64
> 3
Group variable: codpays                                Number of groups =  1
> 4
R-sq: within   =  0.4240                                Obs per group: min  =  4
> 5
between       =  0.6902                                avg         =  45.
> 9
overall       =  0.6704                                max         =  4
> 6

F(7,622)      =  65.4
> 1
corr(u_i, Xb) =  0.0656                                Prob > F       =  0.000
> 0

| ECo2     | Coef. | Std. Err. |     t  |  P>|t| | [95% Conf. Interval]         |
|----------|-------|-----------|--------|------|-----------------------------|
|         |       |           |        |      |                             |
| pib      | -0.0004546 | 0.0001202 | -3.78  | 0.000 | -0.0006907 -0.0002186       |
| pib2     | 1.29e-07  | 1.51e-08  |  8.54  | 0.000 |  9.95e-08  1.59e-07          |
| pib3     | -4.16e-12 | 5.56e-13  | -7.49  | 0.000 | -5.26e-12  -3.07e-12         |
| ce       | 0.0008476 | 0.0001252 |  6.77  | 0.000 |  0.0006018  0.0010934        |
| pernr    | 0.0018314 | 0.0013054 |  1.40  | 0.161 | -0.0007322  0.004395         |
| g        | -0.0018384 | 0.0034118 | -0.54  | 0.590 | -0.0085384  0.0048617        |
| denspop  | -0.0033692 | 0.0012732 | -2.65  | 0.008 | -0.0058695  -0.000869        |
| _cons    | 0.7648925  | 0.175208  |  4.37  | 0.000 |  0.4208216  1.108963         |
| sigma_u  | 1.4020818  |
| sigma_e  | 0.52784295 |
| rho      | 0.87586358 (fraction of variance due to u_i) |

F test that all u_i=0:  F(13, 622) = 124.90  Prob > F = 0.0000
```


Annex 2: Hausman test results

Test: Ho: difference in coefficients not systematic

\[
\text{chi}^2(5) = (b-B)'[(V_b-V_B)^{-1}](b-B)
\]

\[
= 51.41
\]

\[
\text{Prob} \text{chi}^2 = 0.0000
\]

(V_b-V_B is not positive definite)

<table>
<thead>
<tr>
<th>fe</th>
<th>re</th>
<th>Difference</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.004451</td>
<td>-0.000083</td>
<td>-0.003368</td>
<td>0.0000402</td>
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<tr>
<td>1.29e-07</td>
<td>7.64e-08</td>
<td>5.29e-08</td>
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</tr>
<tr>
<td>-4.16e-12</td>
<td>-2.40e-12</td>
<td>-1.77e-12</td>
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</tr>
<tr>
<td>0.0006473</td>
<td>0.00123734</td>
<td>-0.0004261</td>
<td>0.0000458</td>
</tr>
<tr>
<td>0.0018141</td>
<td>0.0035352</td>
<td>-0.0013211</td>
<td></td>
</tr>
<tr>
<td>-0.0018459</td>
<td>-0.0045614</td>
<td>0.0027156</td>
<td></td>
</tr>
<tr>
<td>-0.0033349</td>
<td>-0.001976</td>
<td>-0.0018373</td>
<td></td>
</tr>
</tbody>
</table>

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg
### Annex 3: Robustness check by the two-way fixed effect method

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<thead>
<tr>
<th>Source</th>
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<th>df</th>
<th>MS</th>
<th>Number of obs</th>
<th>644</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>65</td>
<td>60.5638371</td>
<td>248.18</td>
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</tr>
<tr>
<td>Residual</td>
<td>141.047861</td>
<td>578</td>
<td>0.2447241</td>
<td>9.664</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4077.69728</td>
<td>643</td>
<td>6.34167539</td>
<td>4.9399</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>Number of obs</th>
<th>644</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>643</td>
<td>6.34167539</td>
<td>4.9399</td>
<td></td>
</tr>
</tbody>
</table>