

Does the Relationship between Energy Consumption and Greenhouse Gas (CO₂) Emissions in Sub-Saharan Africa Follow a Linear Path?

François Likondzabeka, Antoine Ngakosso, Hermann Clachel Lekana

Laboratory of Economic and Social Analysis and Research, Faculty of Economic Sciences, Marien Ngouabi University, Brazzaville, Republic of the Congo

Email: likondzas@yahoo.fr, antoinengak@gmail.com, hermann.lekana@umng.cg

How to cite this paper: Likondzabeka, F., Ngakosso, A., & Lekana, H. C. (2024). Does the Relationship between Energy Consumption and Greenhouse Gas (CO₂) Emissions in Sub-Saharan Africa Follow a Linear Path? *Journal of Human Resource and Sustainability Studies*, 12, 686-699.
<https://doi.org/10.4236/jhrss.2024.123036>

Received: July 30, 2024

Accepted: September 24, 2024

Published: September 27, 2024

Copyright © 2024 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

The objective of this paper is to determine the inflection point of greenhouse gas (CO₂) emissions in sub-Saharan African countries over the period 2000 to 2018. The strong and weak sustainability theories were used as a framework to analyze this paper. The panel data approach was used, and fixed and random effect models were used. The results obtained show that energy consumption and CO₂ emissions have a non-linear relationship, justifying the existence of an inflection point. These results suggest that, due to a certain level of energy consumption and CO₂ emissions of concern, African countries modify their consumption trajectory by adopting much cleaner energies and by boosting cooperation in environmental preservation.

Keywords

Energy Consumption, CO₂ Emissions, Kuznets Curve, Panel Data, Sub-Saharan Africa

1. Introduction

The problem of CO₂ emissions is now considered a major environmental policy priority, given its weight, which represents nearly three-quarters of the IPCC (2022) gases. Thus, Stern (2016), Nordhaus (2019) and the IPCC (2022) argue that the reduction of CO₂ emissions has beneficial effects on economic growth, well-being, and sustainable development.

Indeed, the latest IPCC report (2022) shows that the increase in CO₂ emissions has negative consequences not only on the climate but also on the econo-

my and the well-being of populations. This is the case of disturbances and/or global warming that are accompanied by droughts, causing famine, reduced productivity of farmers, the retreat of forests or repeated floods. To mitigate these harmful effects, the international community has set the goal of limiting CO₂ emissions to 1000 giga tons by 2100. But, to achieve this, energy consumption must be reduced since, according to the IEA (2014) and more recently Bou-djella and Mugumya (2018) and the IPCC (2022), energy consumption is responsible for two-thirds of CO₂ emissions worldwide. This justifies all the interest given to the relationship between energy consumption and CO₂ emissions, which is the subject of this work.

In the literature, the relationship between energy consumption and CO₂ emissions is at the center of a multitude of reflections. Two points of view clash on the theoretical level. On the one hand, there are the proponents of weak sustainability who admit that the effects of energy consumption on CO₂ emissions can be resolved over time with innovations, complementarity or substitutability of factors creating inflection points (Solow, 1974; Stiglitz, 1974; Romer, 1986; Barro, 1990; Shafik & Bandyopadhyay, 1992; Selden & Song, 1994; Grossman & Krueger, 1995). On the other hand, the proponents of strong sustainability admit that the action of energy is irreversible and, therefore, consumption must be stopped (Georgescu-Roegen, 1979; Passet, 1979; Daly, 1994). On the empirical level, we also find groups of works on the one hand that validate weak sustainability.

On the empirical side, a series of works have been carried out to verify the different approaches to sustainability. Some of them validate strong sustainability, while others validate weak sustainability. Regarding the first work, we can mention those of Zhang and Lin (2012) who analyzed the impact of economic indicators on pollution in Chinese regions over the period from 1995 to 2010. They use a fixed effect model and the generalized least squares method. The main result of this study is that population intensity, GDP, industrial production and energy consumption significantly impact CO₂ emission. Also, using a fixed effect model and ordinary least square (OLS) method, Rafindadi et al. (2014), in their quest on the economic factors likely to cause pollution in Asia Pacific countries over the period of 1975 to 2012, obtained the result that energy consumption positively and significantly impacts on CO₂ emissions. In the same line, Salahuddin and Gow (2019) analyzed the effect of energy consumption and economic growth on environmental quality in Qatar over the period 1980-2016. They use the ARDL model and the Toda Yamamoto causality test to estimate and verify the level of causality. They obtain that in the long run, energy consumption and economic growth positively influence environmental quality and FDI impacts negatively. With regard to causality, they find that there is a bidirectional relationship between the variables. It is noted that in all these works, the consumption of energy is a source of pollution and, therefore, of the destruction of the biosphere (Georgescu-Roegen, 1979). Regarding the second group, we can cite the work of Usman et al. (2019), who also validated the existence of a

CEK in the case of South Africa over the period 1971 to 2014. After the FMLOS estimation, they confirmed the negative effects of energy consumption on environmental degradation. The low long-run elasticity rejects the hypothesis of CEK existence but indicates, however, that the CO₂ emission rate stabilizes in the long run in rich countries. On the other hand, [Abid \(2016\)](#) showed that the Kuznets hypothesis was not proven in the context of the 25 sub-Saharan African states in the period from 1996 to 2010 using the OLS and generalized moments methods (GMM). We note that in this second part, the work validates the vision of weak sustainability with the appearance of turning points that confirm the awareness over time or the use of less polluting factors. [Nkengfack et al. \(2019\)](#) analyzed the effect of economic growth on carbon dioxide emissions in sub-Saharan Africa: Decomposition into scale, composition and technical effects. After estimation, they obtained that economic growth positively influences the environment through the channel of scale and composition effects while the technical effect reduces it.

The theoretical and empirical overview shows that the debate is far from over between energy consumption and CO₂ emissions. The two hypotheses (weak and strong sustainability) remain relevant, especially in recent years, which have been marked by a renewed interest in environmental issues both at the global level and in Africa, which today represent a major challenge in the fight for environmental preservation. It is also noted that the works that have addressed the theme in the context of Africa, do so in the case of a country ([Sarkodie & Ozturk, 2020](#)), a sub-region ([Usman et al., 2019](#)) or a region ([Abid, 2016](#)). Thus, this paper differs from the previous ones in that it increases the value of energy consumption to capture possible changes in economic structure, as it has been proven that a high level of development and accompanies a high energy consumption ([IEA, 2021](#)). In addition, this paper makes a regional study of Sub-Saharan Africa and a comparative study of its different sub-regions to show the sub-regional disparities that Sub-Saharan Africa is experiencing.

Indeed, Africa constitutes an interesting field of investigation for the relationship between energy consumption and CO₂ emissions for at least two reasons.

The first is the increase in energy consumption and CO₂ emissions on the continent in recent years. In this regard, in 2000, 2010 and 2014, energy consumption was 653,601, 685,183 and 688,450 kg of oil equivalent per capita, respectively, an increase over the period (2000-2014) of 5.33%. Similarly, considering the above-mentioned period, CO₂ emissions amounted to 564526.616, 746611.912 and 822819.034 kilotons, an increase of 45.75%. Such developments require special attention. The second is that the African continent has always been committed to the management of environmental problems. Indeed, since the accession to independence of most African countries, several actions in the direction of environmental protection have been taken, including, but not limited to, the African Convention on the Conservation of Nature and Natural Resources in 1968, and the African Ministerial Conference on the Environment

(AMCEN), which was established in December 1985 to promote regional cooperation to meet the environmental challenges facing the region (AMCEN, 2021). These facts show the extent to which the African continent in general and sub-Saharan Africa in particular have made the protection of the environment their main concern.

In view of the above, it is appropriate to say that the African continent in general and particularly sub-Saharan Africa, which is aiming at the industrialization of its economy with a rapidly growing population (2.7% per year, World Bank, 2021), should experience an increasing evolution of its energy consumption needs which would also be accompanied by significant CO₂ emissions. In light of these observations, the question underlying the problem of this work is the following: can the hypothesis of weak sustainability be verified in African countries south of the Sahara? In other words, is there an inflection point in the relationship between energy consumption and CO₂ emissions? Thus, the objective is to determine the inflection point of greenhouse gas (CO₂) emissions in African countries south of the Sahara.

In addition to the first and last sections, which are respectively the introduction, conclusion and policy implications, the remainder of this work is presented as follows: the second section is devoted to the methodology, and the third to the presentation and discussion of the results.

2. Methodology

To achieve the objective of this paper, we build on the work of Fan et al. (2006) and Kpemoua (2016). These authors were inspired by the theoretical model of the STIRPAT approach or the Kaya equation (Kaya, 1990), originally developed by Ehrlich and Holden (1971). Indeed, the Kaya equation aims at explaining the determinants of CO₂ emissions. It is formalized as follows:

$$I_{it} = P_{it} A_{it} T_{it} \quad (1)$$

where, (I): the environmental impact, (P): the size of the population, (A): the level of wealth expressed in income per capita, (T): a factor representing technology. According to Kaya, environmental impact is captured by GHG emissions and is decomposed into four factors: population, GDP per capita, energy intensity (i.e., primary energy consumption per unit of GDP) and carbon intensity (i.e., the level of GHG emissions per unit of primary energy consumption). The Kaya equation can be written in the following initial form:

$$CO_{2it} = IE_{it}^{\alpha_1} PIB_{it}^{\alpha_2} L_{it}^{\alpha_3} IC_{it}^{\alpha_4} \quad (2)$$

Based on Dinda's (2004) critique, several variables can also influence GHG emissions. Thus, we can note by X the set of variables that influence GHGs. Taking this input into account, the equation can be written:

$$CO_{2it} = IE_{it}^{\alpha_1} PIB_{it}^{\alpha_2} L_{it}^{\alpha_3} IC_{it}^{\alpha_4} X_{it}^{\alpha_i} \quad (3)$$

with X : a set of variables consisting of: Urbanization (Ur), Technology (T), Trade openness (Ou) and other variables represented by a constant (α_0). Hence

X can be written:

$$X_{it} = \alpha_0 U_{it}^{\alpha_5} T_{it}^{\alpha_6} O_{it}^{\alpha_7} \tag{4}$$

For Sadorsky (2014), the consideration of urbanization is more interesting than population as a pollution factor. In addition, variables such as export share to GDP and energy intensity will be replaced by trade openness and energy consumption. Affluence and technology factors are captured by gross fixed capital formation (K) respectively. Incorporating these observations, the final equation becomes:

$$CO_{2it} = \alpha_0 CE_{it}^{\alpha_1} PIB_{it}^{\alpha_2} U_{it}^{\alpha_3} IC_{it}^{\alpha_4} U_{it}^{\alpha_5} K_{it}^{\alpha_6} O_{it}^{\alpha_7} \tag{5}$$

Satrovic and Adedoyin (2022) propose to square the energy consumption variable to determine the optimal level capable of degrading the environment. This philosophy is retained in this work. The equation is then written:

$$CO_{2it} = \alpha_0 CE_{it}^{\alpha_1} (CE_{it}^2)^{\alpha_2} PIB_{it}^{\alpha_3} U_{it}^{\alpha_4} O_{it}^{\alpha_5} K_{it}^{\alpha_6} IC_{it}^{\alpha_7} \tag{6}$$

Taking into account some adjustments and the Néperien logarithm of the variables, the function to be estimated to analyze the link between CO₂ emissions, their restriction and economic growth can be written as follows:

$$\ln CO_{2it} = \alpha_0 + \alpha_1 E_{it} + \alpha_2 E_{it}^2 + \alpha_3 y_{it} + \alpha_4 U_{it} + \alpha_5 O_{it} + \alpha_6 k_{it} + \alpha_7 ic_{it} + \varepsilon_{it} \tag{7}$$

with E : log energy consumption, E^2 : log energy consumption squared, y : log GDP, U : log Urbanization; O : log trade openness, k : log gross fixed capital formation and ic : log carbon intensity and ε : error term. The subscript t and i represent time and individual. The parameters, $\alpha_0, \dots, \alpha_7$ are elasticities.

Sub-Saharan Africa has 48 countries that differ in many respects, including geographical, climatic, cooperation, and development aspects. Moreover, they do not use the same energy sources, and consequently, the extent of pollution is not identical, thus raising the problem of individual heterogeneity. In panel data, individual heterogeneity can be taken into account either by introducing random individual specificities or by introducing individual fixed effects. Given the problems inherent in the specification of a fixed-effects model and the restrictive assumption in the specification of a random-effects model that the effects and regressors are uncorrelated, we have chosen to estimate the effects of a fixed-effects model in the panel data. In this paper, we choose to estimate both models, especially since we rely on a geographical grouping of countries in Sub-Saharan Africa. To this end, we will decompose the random disturbance variable. We will then have:

$$\varepsilon_{it} = \alpha_i + \vartheta_{it}$$

Thus, the final model is:

$$\ln CO_{2it} = \alpha_0 + \alpha_1 E_{it} + \alpha_2 E_{it}^2 + \alpha_3 y_{it} + \alpha_4 U_{it} + \alpha_5 O_{it} + \alpha_6 k_{it} + \alpha_7 ic_{it} + \alpha_i + \vartheta_{it} \tag{8}$$

where: α_i and ϑ_{it} are uncorrelated random disturbances and are called individual effect and residual effect, respectively.

Source and Presentation of Data

The data used in this article are extracted from the World Bank website, specifically the [World Bank \(2020\)](#) database. This article focuses on an analysis of panel data consisting of forty-four (44) countries¹ in Sub-Saharan Africa over a period from 2000 to 2018. The length of the study is dictated by data availability.

There are three variables of interest.

CO_2 : is the emission of carbon dioxide, which is taken as a proxy for environmental degradation and measured in metric kilotons.

E : is the energy consumption that is captured by the energy use variable measured in kilotons of oil equivalent (Keq). It includes all energy consumption regardless of the nature of the source. According to Georgescu-Roegen, it has a positive influence on the increase of pollution.

E^2 : is the squared energy consumption variable that allows us to verify the linearity or non-linearity hypothesis.

The other variables are controls, of which we can mention:

y : is GDP which captures economic activity and can positively or negatively affect environmental degradation.

U : Urbanization is the share of the urban population in relation to the total population. According to the literature, it has a positive influence on environmental degradation.

O : is the country's share of world trade as a percentage of GDP, which gives the extent of trade

k : is domestic investment measured by the ratio of gross fixed capital formation to GDP.

ic : is carbon intensity which positively impacts environmental degradation.

3. Presentation and Discussion of the Results

To estimate this equation, specification tests are necessary to obtain the best possible results. These are the Fisher test, which is a test specific to the fixed-effects panel data model; the Breusch and Pagan test (LM-test), which is a test specific to the random-effects panel data; and the Hausman test, which is used to discriminate between fixed- and random-effects models.

Before discussing these tests, we will present the descriptive statistics for the different zones and for Sub-Saharan Africa as a whole.

3.1. Descriptive Statistics

In these sub-sections, we will present the mean and standard deviation tables for the regions of Sub-Saharan Africa and for the region as a whole. The following

¹Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Comoros, Democratic Republic of Congo, Republic of Congo, Cote d'Ivoire, Eritrea, Eswatini, Gabon, Gambia, Ghana, Guinea, Equatorial Guinea, South Africa, Guinea-Bissau, Central African Republic, Chad, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe.

Table 1 presents the mean, standard deviation, minimum, maximum and number of observations for the geographic areas of Sub-Saharan Africa and the world as a whole.

Table 1. Descriptive statistics for Central Africa.

	Variable	Mean	St. dev	Minimum	Maximum	Observations
Central Africa	CO ₂ emission	5622.033	8272.988	168.682	34763.16	N = 152
	CO ₂ intensity	9.910	14.642	1.076	58.684	N = 152
	Energy	760.157	810.757	126.121	3129.892	N = 152
	GFCF	23.747	8.519	6.405	60.156	N = 152
	Constant GDP	2.19e+10	2.35e+10	1.49e+09	1.05e+11	N = 152
	Urbanization	360968.3	287,897	13770.29	1,042,525	N = 152
	Trade openness	84.040	35.347	25.042	165.646	N = 152
West Africa	CO ₂ emission	8591.114	22630.13	146.68	106,068	N = 304
	CO ₂ intensity	15.866	29.317	0.318	144.343	N = 304
	Energy	375.484	179.709	82.003	882.528	N = 304
	GFCF	22.276	10.257	1.097	61.469	N = 304
	Constant GDP	2.92e+10	8.36e+10	6.60e+08	4.69e+11	N = 304
	Urbanization	136593.7	154704.6	2153.428	553197.2	N = 304
	Trade openness	71.674	35.3611	20.723	311.354	N = 304
East Africa	CO ₂ emission	4011.708	4439.726	102.676	15940.45	N = 285
	CO ₂ intensity	8.880	9.440	0.242	42.016	N = 285
	Energy	538.575	501.913	111.5003	3015.527	N = 285
	GFCF	21.822	9.601	1.525	53.988	N = 285
	Constant GDP	1.55e+10	1.71e+10	7.02e+08	7.94e+10	N = 285
	Urbanization	133263.5	167859.8	231.993	653371.7	N = 285
	Trade openness	64.634	40.418	19.101	225.023	N = 285
Southern Africa	CO ₂ emission	92380.22	181388.3	1015.759	503112.4	N = 95
	CO ₂ intensity	36.611	67.589	1.020	185.110	N = 95
	Energy	1219.277	736.151	575.074	2947.613	N = 95
	GFCF	23.274	6.7623	11.824	41.412	N = 95
	Constant GDP	7.83e+10	1.44e+11	1.65e+09	4.30e+11	N = 95
	Urbanization	290,788	279129.2	3789.523	808927.2	N = 95
	Trade openness	96.933	29.274	51.078	175.798	N = 95

Continued

Sub-Saharan Africa	CO ₂ emission	16011.61	68273.03	102.676	503112.4	N = 836
	CO ₂ intensity	14.759	31.082	0.24171	185.110	N = 836
	Energy	596.910	587.545	82.003	3129.892	N = 836
	GFCF	22.502	9.398	1.097	61.469	N = 836
	Constant GDP	2.87e+10	7.36e+10	6.60e+08	4.69e+11	N = 836
	Urbanization	193775.9	225005.9	231.993	1,042,525	N = 836
	Trade openness	74.393	37.970	19.101	311.354	N = 836

Source: Authors using data from [World Bank \(2020\)](#).

The descriptive statistics of the different SSA regions and the whole show that the average levels of the variables are higher in Southern Africa (SA), except for trade openness and urbanization in Central Africa (CA). However, it should be mentioned that the average level of energy consumption in Southern Africa and West Africa (WA) is lower than in SSA and the average level of the CO₂ emission variable in SSA is higher than in East Africa (EA), CA and WA. In terms of dispersion, the EI region followed by CA has the highest concentration around the mean. The SA and WA regions show high dispersion on variables such as CO₂ emissions, CO₂ intensity, and GDP. A reading of SSA reveals that the sub-region is highly dispersed except for energy consumption, urbanization and trade openness. In conclusion, a reading of the descriptive statistics shows the divergences between the SSA regions and in its entirety. To this end, a grouped analysis should bias the individual results of the regions, which in a way confirms the approach adopted in this work.

3.2. Results of the Fischer and Breusch and Pagan Tests

These two tests validate the existence of either fixed effects (Fischer test) or random effects (Breusch and Pagan test). They are respectively based on two hypotheses, namely the null hypothesis (absence of fixed effects and random effects) and the alternative hypothesis (presence of fixed effects and random effects). The results of the tests are summarized in [Table 2](#) below:

Table 2. Summary result of Fischer and Breusch-Pagan tests.

Regions	Test of Fisher	Test of Breusch-Pagan
Central Africa	Prob > F = 0.0000	Prob > chibar2 = 0.0000
West Africa	Prob > F = 0.0000	Prob > chibar2 = 0.0000
East Africa	Prob > F = 0.0000	Prob > chibar2 = 0.0000
Southern Africa	Prob > F = 0.0000	Prob > chibar2 = 1.0000
Sub-Saharan Africa	Prob > F = 0.0000	Prob > chibar2 = 0.0000

Source: Authors based on estimation results.

A reading of the summary table of the results of the Fischer-Breusch-Pagan test shows that whatever the region, the probability of the calculated Fischer statistic is less than 1%. Therefore, the H0 hypothesis is rejected, and the effects model is more appropriate. The results of the Breusch-Pagan tests show two cases. The first is that there are random effects that are significant at the 1% level for the CA, EA, WA and SSA regions. However, in the second case, which consists of the Southern Africa sub-region, the null hypothesis of no random effects is not rejected because the probability of the statistic is higher even at the 10% level.

3.3. Hausman Test

The Hausman test allows us to test the presence of a correlation or not between the specific effects and the explanatory variables of the model. This makes it possible to choose between the fixed effects model and the random effects model (Kpodar, 2007). This test has two hypotheses, H0: There is no systematic difference in coefficients and H1: There is a difference between the coefficients. The results of the Hausman test are presented in the estimation table.

Reading the Hausman test results reveals that in the majority of regions, the fixed-effects model is more appropriate than the random-effects model, because the probability of the test statistic is less than 1%. However, in the case of CA, the opposite is true. In view of the results of the various tests mentioned above, we will estimate two models: fixed effects and random effects in this article. **Table 3** below presents the results of the estimations of the fixed and random effects models.

Table 3. Estimation results.

	Central Africa	West Africa	East Africa	Southern Africa	Sub-Saharan Africa
Energy consumption	5.596 (8.21)***	-1.508 (-1.87)*	-2.787 (-6.74)***	-4.164 (-2.62)**	0.403 (0.84)
Square energy consumption	-0.401 (-7.9)***	0.196 (2.61)**	0.265 (9.03)***	0.353 (3.09)***	0.00027 (0.995)
Gross domestic product	1.192 (16.35)***	0.748 (4.97)***	0.599 (10.14)***	-0.138 (-1.38)	0.743 (13.77)***
Urbanization	-0.224 (-0.88)	0.061 (0.29)	0.996 (5.28)***	1.326 (5.44)***	0.466 (3.21)***
Trade openness	0.272 (3.34)***	0.170 (4.57)***	0.316 (7.31)***	-0.005 (-0.07)	0.207 (6.47)***
Gross fixed capital formation	-0.071 (-1.15)	0.136 (4.97)***	-0.098 (-2.75)**	0.131 (1.82)*	0.005 (0.21)

Continued

Constant	-37.088 (11.24)***	-9.004 (-3.44)***	-10.184 (-4.82)***	8.516 (1.58)	-17.720 (-10.21)***
Threshold	1069.060	46.510	192.349	363.705	
% R2	75.4	78.3	98.7	99.9	98.9
Fischer		205.35	159.23	60.02	176.01
Prob (F)		0.000	0.000	0.000	0.000
Wald	705.49				
Prob	0.000				
Hausman	1.36	128.31	59.50	27.11	19.90
Prob (hausman)	0.968	0.000	0.000	0.000	0.003
Obs	152	304	285	95	836

Source: Authors based on estimation results. Values in parentheses are student's statistics and *, ** and *** represent the 10%, 5% and 1% thresholds respectively.

3.4. Analysis and Interpretation of Results

The reading of the estimation results presented in the table above shows that the R²s are greater than 50% whatever the model and that the Wald test is very conclusive for the random effect models. In light of these indicators, we can proceed to the analysis and interpretation of the results. Except for the SSA equation, all SSA regions have thresholds that are either a minimum or a maximum. The region with a maximum is CA with a threshold of 1069.060 Kep. The others, on the other hand, have minimums, namely WA (46.510 Kep), EA (192.349 Kep) and SA (363.705 Kep). All these results allow us to draw a major lesson:

The relationship between energy consumption and environmental degradation is not linear.

The results revealed the existence of turning points in the different regions of SSA. These results confirm Rostow's 1960 theory of structural development and its critics. Indeed, we can assume that CEK is an extension of Rostow's theory (Barthélemy, 1995).

In CA, the inverted U-shape states that an increase in the level of energy consumption leads to an increase in the level of CO₂ emissions until a turning point is reached at which this level starts to fall and then begins to fall. This situation is explained by the fact that during the upward period, the economies of these countries will increase their consumption by moving from the primary sector to a secondary or even tertiary sector. However, once the turning point is reached, they will accentuate social policies that are more concerned with the environment, which will explain the downward phase. On a factual level, it is worth noting that, for almost a decade, CA economies have been the engine of economic growth in SSA, with levels reaching double digits. This period favored the

attraction of FDI in the primary commodities and infrastructure sectors. All of these transformations have led these economies to migrate from the primary phase to the secondary and tertiary phases, thus pushing governments to implement increased social policies.

For other regions, however, the U-shape, commonly referred to as the inverted J-shape, is the critique of the Rostow model. Indeed, according to the proponents of this critique, the structure of countries is a fundamental element of any economy. Thus, an increase in energy consumption in its regions will lead to a decrease in CO₂ emissions until the turning point is reached, when the latter will start to increase. This situation can be explained by the acceptance theory or by the vision of clean energy. Indeed, during the downward phase, the increase in energy consumption will undergo a phase of acceptance or reduction of the energies that are not suitable for the atmosphere until the minimum point is reached, and once accepted, the consumption of the latter should start to increase. From a factual point of view, this situation can be explained by the fact that SA, EA and WA are regions of SSA where the consumption of unsuitable energy is high. In fact, in AA, electricity production is mainly derived from coal-fired power plants, accounting for more than 80%. A study conducted by the United Nations Environment Programme (UNEP, 2017) showed that EA and WA are the most polluting regions of SSA, due to the increased use of firewood. In the same study, it is revealed that about 90% of the population is exposed to air pollution in households consuming this type of energy. As a result, the government has embarked on extensive clean electrification programs and the shutdown of coal-fired power plants. We notice that the population plays an important role in CO₂ emissions, which is confirmed in this study with the variable urbanization.

4. Conclusion and Policy Implications

The objective of this paper was to determine the level of energy consumption that would minimize CO₂ emissions in forty-four (44) Sub-Saharan African countries over the period 2000 to 2018. After mobilizing fixed and random effects models, the results show that the relationship between energy consumption and CO₂ emissions is not linear in the SSA regions, but there is no relationship at the SSA level as a whole.

In light of the lessons learned, two main policy implications were formulated. The first is a policy that focuses on energy efficiency and cleaner consumption (Lekana, 2020). Indeed, SSA countries must orient their energy policies towards more rational and cleaner energy consumption. To do this, governments must diversify the energy portfolio and utilize the vast untapped renewable energy potential to achieve a balance between energy consumption, economics and environmental benefits for the continent and SSA in particular. The second is a policy of intergovernmental cooperation. Indeed, policymakers need to bring their vision together by region and not for all of SSA. Thus, they need to develop environmental policies that focus on specific objectives for each subregion. Giv-

en the influence of energy consumption on the environment, it would be wise to also consider its effects on human capital in Africa.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- Abid, M. (2016). Impact of Economic, Financial, and Institutional Factors on CO₂ Emissions: Evidence from Sub-Saharan Africa Economies. *Utilities Policy*, *41*, 85-94. <https://doi.org/10.1016/j.jup.2016.06.009>
- AMCEN (2021). *The Ministerial Segment of the Eighteenth Session of the African Ministerial Conference on the Environment (AMCEN)*. 16 September 2021.
- Barro, R. J. (1990). Government Spending in a Simple Model of Endogeneous Growth. *Journal of Political Economy*, *98*, S103-S125. <https://doi.org/10.1086/261726>
- Barthélemy, P. (1995). L'hypothèse de Kuznets est-elle encore d'actualité? *Région & Développement*, *2*, 1-23.
- Boudjella, A., & Mugumya, A. (2018). Modelling Electricity Generation and Capacity with CO₂ Emissions for Sub Saharan Africa. *Open Journal of Statistics*, *8*, 861-872. <https://doi.org/10.4236/ojs.2018.85057>
- Daly, H. (1994). Operationalizing Sustainable Development by Investing in Natural Capital, In A. M. Jansson, M. Hammer, C. Folke, & R. Costanza (Eds.), *Investing in Natural Capital: The Ecological Economics Approach to Sustainability* (pp. 22-37). Island Press.
- Dinda, S. (2004). Environmental Kuznets Curve Hypothesis: A Survey. *Ecological Economics*, *49*, 431-455. <https://doi.org/10.1016/j.ecolecon.2004.02.011>
- Ehrlich, P. R., & Holdren, J. P. (1971). Impact of Population Growth. *Science*, *171*, 1212-1217. <https://doi.org/10.1126/science.171.3977.1212>
- Fan, Y., Liu, L., Wu, G., & Wei, Y. (2006). Analyzing Impact Factors of CO₂ Emissions Using the STIRPAT Model. *Environmental Impact Assessment Review*, *26*, 377-395. <https://doi.org/10.1016/j.eiar.2005.11.007>
- Georgescu-Roegen, N. (1979). Myth about Energy and Matter. *Growth and Change*, *10*, 16-23. <https://doi.org/10.1111/j.1468-2257.1979.tb00819.x>
- Grossman, G. M., & Krueger, A. B. (1995). Economic Growth and the Environment. *The Quarterly Journal of Economics*, *110*, 353-377. <https://doi.org/10.2307/2118443>
- IEA (2014). *World Energy Outlook 2014*. IEA. <https://www.iea.org/reports/world-energy-outlook-2014>
- IEA (2021). *Annual Energy Outlook 2021*. Bipartisan Policy Center.
- IPCC (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability Report Climate Change 2022: Impacts, Adaptation and Vulnerability*.
- Kaya, Y. (1990). *Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios*. The IPCC Energy and Industry Sub-Group, Response Strategies Working Group.
- Kpemoua, P. (2016). *Analyse du lien entre les émissions de CO₂, leur restriction et la croissance économique du Togo*. <https://mpr.ub.uni-muenchen.de/77624/>
- Kpodar, K. (2007). *Manuel d'Initiation à Stata (Version 8)*. CERDI.

- Lekana, H. C. (2020). Energy Consumption and Economic Development in Sub-Saharan African Countries: Role of Governance Quality. *Modern Economy, 11*, 1901-1918. <https://doi.org/10.4236/me.2020.1111127>
- Nkengfack, H., Fotio, H. K., & Djoudji, S. T. (2019). The Effect of Economic Growth on Carbon Dioxide Emissions in Sub-Saharan Africa: Decomposition into Scale, Composition and Technique Effects. *Modern Economy, 10*, 1398-1418. <https://doi.org/10.4236/me.2019.105094>
- Nordhaus, W. (2019). Climate Change: The Ultimate Challenge for Economics. *American Economic Review, 109*, 1991-2014. <https://doi.org/10.1257/aer.109.6.1991>
- Passet, R. (1979). *L'Economique et le Vivant* (2nd ed.). Payot. [Spanish Edition: Principios de Bioeconomia, Argentaria, Madrid].
- Rafindadi, A. A., Yusof, Z., Zaman, K., Kyophilavong, P., & Akhmat, G. (2014). The Relationship between Air Pollution, Fossil Fuel Energy Consumption, and Water Resources in the Panel of Selected Asia-Pacific Countries. *Environmental Science and Pollution Research, 21*, 11395-11400. <https://doi.org/10.1007/s11356-014-3095-1>
- Romer, P. M. (1986). Increasing Returns and Long-Run Growth. *The Journal of Political Economy, 94*, 1002-1037. <https://www.parisschoolofeconomics.eu/docs/darcillon-thibault/paul-romer-increasing-returns-and-long-run-growth.pdf>
- Sadorsky, P. (2014). The Effect of Urbanization on CO₂ Emissions in Emerging Economies. *Energy Economics, 41*, 147-153. <https://doi.org/10.1016/j.eneco.2013.11.007>
- Salahuddin, M., & Gow, J. (2019). Effects of Energy Consumption and Economic Growth on Environmental Quality: Evidence from Qatar. *Environmental Science and Pollution Research, 26*, 18124-18142. <https://doi.org/10.1007/s11356-019-05188-w>
- Sarkodie, S. A., & Ozturk, I. (2020). Investigating the Environmental Kuznets Curve Hypothesis in Kenya: A Multivariate Analysis. *Renewable and Sustainable Energy Reviews, 117*, Article ID: 109481. <https://doi.org/10.1016/j.rser.2019.109481>
- Satrovic, E., & Adedoyin, F. F. (2022). An Empirical Assessment of Electricity Consumption and Environmental Degradation in the Presence of Economic Complexities. *Environmental Science and Pollution Research, 29*, 78330-78344. <https://doi.org/10.1007/s11356-022-21099-9>
- Selden, T. M., & Song, D. (1994). Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions? *Journal of Environmental Economics and Management, 27*, 147-162. <https://doi.org/10.1006/jeem.1994.1031>
- Shafik, N., & Bandyopadhyay, S. (1992). *Economic Growth and Environmental Quality Time-Series and Cross-Country Evidence*. World Bank Working Papers 904.
- Solow, R. M. (1974). The Economics of Resources or the Resources of Economics. *The American Economic Review: Papers and Proceedings, 64*, 1-14.
- Stern, N. (2016). Economics: Current Climate Models Are Grossly Misleading. *Nature, 530*, 407-409. <https://doi.org/10.1038/530407a>
- Stiglitz, J. (1974). Growth with Exhaustible Natural Resources: Efficient and Optimal Growth Paths. *The Review of Economic Studies, 41*, 123-137. <https://doi.org/10.2307/2296377>
- UNEP (2017) *Annual Report 2017*. <https://www.unep.org/annualreport/>
- Usman, O., Iorember, P. T., & Olanipekun, I. O. (2019). Revisiting the Environmental Kuznets Curve (EKC) Hypothesis in India: The Effects of Energy Consumption and Democracy. *Environmental Science and Pollution Research, 26*, 13390-13400. <https://doi.org/10.1007/s11356-019-04696-z>

World Bank (2021). *Global Economic Prospects*. International Bank for Reconstruction and Development.

World Bank (2020). *World Development Indicators*. DataBank.

<https://databank.worldbank.org/source/world-development-indicators>

Zhang, C., & Lin, Y. (2012). Panel Estimation for Urbanization, Energy Consumption and CO₂ Emissions: A Regional Analysis in China. *Energy Policy*, 49, 488-498.

<https://doi.org/10.1016/j.enpol.2012.06.048>