"Revisiting the environmental Kuznets curve: Evidence from West Africa"

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REVISITING THE ENVIRONMENTAL KUZNETS CURVE: EVIDENCE FROM WEST AFRICA

Abstract

This paper analyzes the revenue-pollution relationship by revisiting the Environmental Kuznets Curve (EKC) hypothesis for West African countries over the period of 1980–2014. The study approximates the income measurement by GDP per capita and uses carbon dioxide (CO_2), nitrogen oxide (NO_2), and methane emissions as various environmental quality measures. The paper uses parametric and non-parametric estimation techniques to test the EKC hypothesis. The results support the existence of the U-inverted relationship between income and methane emission, on one hand, and between income and nitrogen dioxide emission on the other. The estimates also show a mixed result for the U-inverted hypothesis between income and carbon dioxide emissions. Thus, the verification of the curve depends on the estimation techniques and the measurement of the pollutant used. The obtained results led to the conclusion that the EKC hypothesis is validated for West African countries.

Keywords	Environmental Kuznets Curve (EKC), ECOWAS, climate change, economic growth, energy consumption
JEL Classification	Q50, Q56, O10, O13

INTRODUCTION

Since the early work (Grossman & Krueger, 1991; Holtz-Eakin & Selden, 1995), the Environmental Kuznets Curve (EKC) hypothesis has given rise to several empirical works in economics and other related sciences. For some authors, the growth of economic activities requires more significant inputs of energy and materials. This growth is driven by industrialization, which is expected to generate more substantial quantities of liquid, gaseous, and solid waste by-products. The accumulation of these wastes contributes to environmental degradation and, thus, to the degradation of the well-being of earth's inhabitants, despite the steady rise in countries' incomes. This work proves that the degradation of the resource base will eventually put economic activity at risk. Thus, to save both the economy and the environment, countries need to slow down their growth, and the world needs to transition to a sustainable economy.

On the other hand, other researchers argue that the fastest route to an improved environment is economic growth. With higher incomes, there is an increased demand for less material-intensive goods and services and a demand for enhanced environmental quality, leading to the adoption of environmental protection measures. The goal of any economy is to achieve a desirable and sustainable economic growth and development level. However, the environment's quality varies according to the various stages, patterns, and structures of development that each country wishes to achieve. Thus, although economic growth

usually leads to environmental deterioration in the early stages of the development process, the best way to achieve a decent environment in most countries is to become rich. The central issue is the evidence of the Environmental Kuznets Curve (EKC), which assumes that at low-income levels, an increase in national income is accompanied by increased environmental pressure in the form of an inverted U-shape. This relationship thus described is generally known as the Environmental Kuznets Curve (EKC).

Empirical studies support an inverted U-shaped relationship between environmental degradation and economic growth (Grossman & Krueger, 1991). On the other hand, others highlight the existence of a bell-shaped relationship between levels of environmental quality and per capita income. Azomahou et al. (2006) and Stern (2004) find that GDP growth rates do not play significant role in environmental quality dynamics.

In the context of African countries, studies on the EKC hypothesis are far from reaching a consensus. In the case of organic pollutants in water, their paper suggests a positive connection when Osabuohien et al. (2014) establish the existence of an Environmental Kuznets curve for CO2 emissions.

Over the period 2010–2018, the Member States of Economic Community of West African States (ECOWAS) achieved average real GDP growth of 3.8% against 2.7% for the whole of Africa (WDI, 2020). The rates for energy consumption and carbon dioxide emission for the ECOWAS region also exploded over this period. Data from the Notre Dame University Global Climate Change Adaptation Indicator (ND-GAIN) confirms that despite notable progress since 2008, the ECOWAS region is highly vulnerable to climate change and has very low resilience to climate-related risks. For instance, the vulnerability of ECOWAS in 2018 was 0.547 against 0.442 for the world, while the resilience to climate risks was 0.309 versus 0.427 for the world (ND-GAIN Country Index, 2018). Therefore, there is a need for ECOWAS countries to pursue policies within the framework of the commitments made in the United Nations 2030 agenda and the Paris Climate Agreement for economic development with less polluting gases.

However, given the mixed results of empirical studies on the link between economic growth and the emission of polluting gases, it is necessary to investigate this link within the ECOWAS framework to assess the policies' effectiveness. In doing so, is the hypothesis of the environmental Kuznets curve in inverted U shape verified in ECOWAS countries? This paper's main objective is to determine the relationship between GDP, energy intensity, sectoral value added in services, industry, CO2, NO2, and Methane emissions in ECOWAS countries. At the end of the study, it emerges that the environmental Kuznets curve is verified for ECOWAS. However, the results are dependent on the pollutant used and the estimation techniques implemented.

The paper is organized as follows:

1) literature review,
2) methodology of analysis,
3) empirical results,
4) conclusion.

1. LITERATURE REVIEW

Since Grossman and Krueger (1991), several empirical studies have tested the relationship between growth and the environment in several other countries by including other indicators. The research hypothesis in these various studies is the "Environmental Kuznets Curve (EKC)" hypothesis. This hypothesis postulates that the relationship between income (often captured by real Gross Domestic Product (GDP) per capita) and pollution approximated by the concentration of a par-

ticular pollutant is an inverted U-shaped curve. According to Kuznets (1955), increasing income levels increase environmental pollution in the first phase of the development process. Beyond an income threshold, the second phase is marked by a decrease in ecological degradation (pollution) due to the adoption of efficient technologies in the production process.

At the empirical level, the analysis of the EKC hypothesis has provided mixed results (Effiong & Oisaozoje, 2016) due to economies' divergence. On one hand, empirical studies provided unclear results and, on the other hand, increasingly intense and precise criticisms of the estimation techniques. One reason put forward by Effiong and Oisaozoje (2016) to justify these mixed results is the diversity of variables used as a proxy of environmental quality and the econometric estimation techniques employed. Findings can be grouped into two categories.

The first group of studies has concluded that the EKC hypothesis has been verified in certain countries or groups of countries (Lamla, 2009; Rosado, 2017; Shahbaz et al., 2013). A second group had mixed results or did not validate the EKC hypothesis. In particular, several studies show that the EKC hypothesis tests are mixed (Dinda, 2004; Effiong & Oisaozoje, 2016). Osabuohien et al. (2014) confirm the EKC hypothesis's validity for PM10 particles and carbon dioxide (CO_2) to indicate environmental pollution.

1.1. Empirical work using parametric estimation models

Several approaches have been used to test the EKC hypothesis. N'Zué (2018) used an ARDL modeling to assess the EKC hypothesis for CO_2 in Côte d'Ivoire. Keho (2017) used an estimation technique based on quantile regressions to establish a relationship between income and CO_2 emissions for 59 countries divided into five groups. The energy consumption leads to an increase in CO_2 emissions in all groups, and even more so in the less polluting countries.

Moreover, for all the quantiles considered, Kuznets' hypothesis is particularly true for Sub-Saharan Africa. By controlling for income heterogeneity

in African countries, Ogundipe et al. (2014) show that the EKC hypothesis is only valid if only lower-middle-income countries are considered. In contrast, for all African nations and those with low and upper-middle-income, the EKC hypothesis test is invalid.

1.2. Empirical work using non-parametric or semi-parametric estimation models

In parallel to studies that used parametric estimation methods, other papers tested the pollution-income nexus through more flexible estimation techniques (non-parametric and semi-parametric). The choice of an estimation methodology has sometimes been criticized in the literature. Stern (2004) details why the statistical and econometric analysis on which the Environmental Kuznets Curve is based is not robust. He highlighted heteroskedasticity problems, simultaneity, cointegration, or bias due to omitted variables. Other issues arise from the reduced-form analysis. The choice of functional form (quadratic or cubic) also affects the result obtained and determines the number of inflection points that appear (Kijima et al., 2010). Indeed, if the estimators are significant and have the expected sign, a quadratic form implies an environmental Kuznets curve. In contrast, a cubic shape imposes the N-shaped curve. Thus, several works overcome this restriction of the functional form by using non-parametric methods (semi-parametric panel with fixed effects), which have the advantage of being more robust.

Using this method, Bertinelli and Strobl (2005) establish a positive link between wealth and environmental degradation for very developing countries and fail to reach a clear conclusion for developed countries. Several works have used these estimation techniques. Effiong and Oisaozoje (2016) used the same approach specifically for 49 African countries between 1990 and 2010 to conclude that economic growth is insufficient to determine environmental quality. Instead, the environmental effects of growth are highly dependent on the type of pollutant used. Several other studies following this logic validate the EKC hypothesis for countries with a per capita GDP of more than USD 5,000 (Azomahou et al., 2006; Luzzati & Orsini, 2009; Nguyen Van & Azomahou, 2007). Bertinelli

and Strobl (2005), using a semi-parametric, partially linear, fixed-effect model, support a positive low-income relationship that flattens out before rising again for higher incomes. L. Chen and S. Chen (2015) examine and find an inverted U-shaped relationship for 31 Chinese provinces. Wang et al. (2016) establish evidence of an inverted U-curve using the estimators of Baltagi and Li (2002) on a semi-parametric fixed-effects model and by measuring sulfur dioxide (SO2) pollution.

Furthermore, several authors argue that industrialization and globalization also have a role in determining whether or not the environment's quality is preserved. Copeland and Taylor (1995) indicated that globalization facilitated the transfer of pollution-intensive technologies to (developing) countries with weak environmental regulations. Developed countries in such circumstances derive significant benefits from trade openness at the expense of the environment in developing economies. On the other hand, Antweiler et al. (2001) and Liddle (2001) argue that trade opening somewhat improves the environment's quality through the technical effect. Some authors have also included sectoral added values in analyzing the environmental Kuznets curve (N'zué, 2018).

It emerges from this review that no consensus emerges from the empirical work results on testing the Environmental Kuznets Curve hypothesis. Some works validate the EKC thesis, while others refute it. This paper also used several indicators like Yusuf et al. (2020) to measure the degradation of environmental quality (Carbon Dioxide (CO2), nitrous oxide (NO2), Methane, PM10) through several parametric methods (fixed and random effects models, Autoregressive Distributed Lag Model (ARDL), quantile regressions, etc.) and semi-parametric methods.

2. DATA AND METHODOLOGICAL FRAMEWORK OF THE STUDY

2.1. Data source

This paper focuses on ECOWAS[1] countries except for Liberia and uses data from two (2) sources: the World Bank (World Development Indicators, 2020) and the International Energy Agency (IEA). Data on emissions of carbon dioxide (CO2), nitrogen dioxide (NO2), methane, real Gross Domestic Product, sectoral added values come from the World Development Indicators (WDI) and total final energy consumption from the International Energy Agency (IEA). The sample covers the period 1980–2014. The study's end period is 2014 because data on CO2, NO2, and methane emissions are only available until 2014 for all countries. Variables used in the paper are defined as follows (Table 1).

Following the recent literature on the Environmental Kuznets Curve study, the paper uses the emission of CO2, NO2, and methane as the different proxies of environmental degradation. Real Gross Domestic Product per capita measures income. Energy consumption is approximated by total final energy consumption, and sectoral activities are measured by sector value-added as a percentage of GDP. In Tables 2 and 3, descriptive statistics and

Table 1. Variables and units of measure

Source: Authors' elaboration.

Variable	Description	Unit of measure
E	Energy consumption	Kg of oil equivalent per capita
Indva	Industrial Value Added	Percentage of GDP
Serva	Services Value Added	Percentage of GDP
Y	Gross Domestic Product per capita	Constant 2010 USD
CO2	Carbon dioxide emission	Metric tons per capita
NO2	Nitrous oxide emission	Thousand metric tons of CO2 equivalent
Methane	Methane emission	Kt of CO2 equivalent

1 ECOWAS includes 15 West African countries: Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo.

Table 2. Descriptive statistics

Variable	Mean	Std. dev.	Min	Max
CO2 (metric tons per capita)	0.28	0.21	0	1.23
Energy (kg of oil per capita)	334,043.1	938,477.20	1,609.54	4,858,124.7
GDP per capita (USD)	883.12	628.45	272.99	3,468.67
Methane (kt of CO2 equivalent)	12,658.13	20,677.77	83.23	102,391
NO2 (thousand metric tons of CO2 equivalent)	5,168.76	7,235.99	44.06	46,431.49
Indva (%GDP)	20.82	6.53	6.55	38.81
Serva (%GDP)	44.22	10.8	12.44	72.59

Table 3. Correlations

Variables	CO2	Energy	GDP per capita	Methane	NO2	Indva	Serva
CO2	1.00	–	–	–	–	–	–
Energy	0.37	1.00	–	–	–	–	–
	(0.00)	–	–	–	–	–	–
GDP per capita	0.85	0.42	1.00	–	–	–	–
	(0.00)	(0.00)	–	–	–	–	–
Methane	0.31	0.95	0.37	1.00	–	–	–
	(0.00)	(0.00)	(0.00)	–	–	–	–
NO2	0.32	0.87	0.40	0.89	1.00	–	–
	(0.00)	(0.00)	(0.00)	(0.00)	–	–	–
Indva	0.22	0.35	0.23	0.45	0.31	1.00	–
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	–	–
Serva	0.44	0.02	0.47	−0.02	−0.01	−0.15	1.00
	(0.00)	(0.73)	(0.00)	(0.65)	(0.84)	(0.01)	–

the correlation matrix are presented. The correlation matrix reveals a significant positive relationship between CO2, NO2, methane emissions, energy consumption, and real GDP per capita.

2.2. Method of analysis

2.2.1. Theoretical framework and empirical specification of the model

The paper uses the Ehrlich and Holdren (1971) model as a theoretical framework to analyze the relationship between income and environmental quality measured by CO2, NO2, or methane emissions. This model makes it possible to describe ecological changes induced by human activities by relating environmental quality to variables such as population, income, and technological level. This model is translated into the following equation:

$$I = P \cdot A \cdot T, \qquad (1)$$

where I – the variable measuring environmental impact; P – the population's size; A – the variable measuring human economic activity; and T – the technological level per unit of consumption

and production. This model has been improved by Dietz and Rosa (1997) and York et al. (2003). Indeed, the *IPAT* model has been criticized as an identity mathematical model and rigid in proportionality restrictions between variables. As a result, its first improvement proposed by Dietz and Rosa (1997) resulted in a flexible, more improved model called STIRPAT, which makes it possible to analyze environmental impacts. The equation translates this:

$$I_i = aP_i^b A_i^c T_i^d \varepsilon_i. \qquad (2)$$

The variables I, P, T, and A remain the same as those in the IPAT model. But a, b, c, and d represent the model parameters. ε_i is the idiosyncratic error term; i refers to the units of observation. By taking the logarithm of equation (2), a relationship is obtained, which is translated by the following equation (3):

$$LnI_i = \lambda + b \cdot LnP_i + c \cdot LnA_i + d \cdot LnT_i + Ln\varepsilon_i. \qquad (3)$$

York et al. (2003) maintain, following the previous authors, that the quadratic terms of the variables P, A, and T can be added to the STIRPAT model to

be refined. Incorporating the quadratic terms in equation (3) allows variable A to grasp the possible existence of the environmental Kuznets curve hypothesis (EKC), i.e., an inverted U-shaped relationship. Thus, the York et al. (2003) model's theoretical consideration allows considering the following model to analyze the Environmental Kuznets Curve (EKC) hypothesis in the ECOWAS region. The model to be estimated is as follows:

$$LnC_{it} = \beta_1 LnE_{it} + \beta_2 LnIndva_{it} +$$
$$+\beta_3 LnServa_{it} + \beta_4 LnY_{it} + \quad\quad (4)$$
$$+\beta_5 [LnY_{it}]^2 + \alpha_i + \tau_t + \varepsilon_{it},$$

where C_{it} – is the variable for measuring the quality of the environment; E_{it} – is the total final energy consumption (Terajoules); $Indva_{it}$ – is the value-added of the industrial sector as a proportion of GDP; $Serva_{it}$ – is the value-added of the service sector as a proportion of GDP. Yit – real GDP per capita; α_i represents the specific effect to each country; τ_t – time effect variable to account for omitted time-varying variables and stochastic shocks common to all nations; i – is the individual dimension representing countries; and t represents time.

The income's effect on the quality of the environment distinguishes two (2) cases according to the sign and significance of the parameters β_4 and β_5. The first case is where $\beta_4 > 0$ ($\beta_5 < 0$ respectively) and $\beta_5 = 0$, then the relationship increases monotonically (respectively decreases). The second case is the one in which we have $\beta_4 = 0$ and $\beta_5 < 0$, on the one hand, and $\beta_4 > 0$ and $\beta_5 < 0$, on the other. In this case, an inverted U-shaped relationship is observed between income and CO2 emission, and the turning point is given by:

$$H^* = -\frac{\beta_5}{2\beta_6}. \quad\quad (5)$$

2.2.2. Econometric estimation methods

The study uses fixed-effect (FE) models, random-effect models, and a semi-parametric estimation technique (SEMI-PARA) based on panel data. The advantage of using a semi-parametric estimation technique is that it makes no assumptions about

the functional form between income and the measurement of environmental degradation (CO2 emissions, for example). The relationship tested is more flexible because the functional form's estimation depends on the sample data. Following the example of Effiong and Oisaozoje (2016), let us specify a semiparametric partially linear fixed-effects model as follows:

$$LnC_{it} = \beta1\, LnE_{it} + \beta2\, LnIndva_{it} +$$
$$+\beta3\, LnServa_{it} + m(LnY_{it}) + \quad\quad (6)$$
$$+\alpha_i + \tau_t + \varepsilon_{it},$$

where m (.) is an unknown smooth function that is sought to be estimated and depends only on income while the other variables in the specification are specified parametrically. Equation (6) is estimated by the method of Baltagi and Li (2002), which is carried out in two steps. In the first step, the parameters of the variables specified in the model's parametric way are estimated. Parameters estimated in the first step allow the m (.) curve estimate by the kernel's regression method or the spline[2].

3. EMPIRICAL RESULTS

This section is devoted to the presentation and discussion of the results. These are the panel estimation results of Ordinary Least Squares (OLS) model, the fixed-effects model, the random-effects model, and the semi-parametric fixed-effects model. The estimation results of these different models are presented in Tables 4, 5, and 6.

3.1. Modelling using CO2 emissions as a measure of environmental degradation

When CO2 emissions are considered ecological quality indicators, total energy consumption is significant for all estimation techniques (at the 1% and 10% threshold). This result is consistent with those of Effiong and Oisaozoje (2016), showing that an increase in energy consumption contributes to a rise in CO2 emissions and environmental quality destruction. As for the sector added values considered,

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2   For the estimation method of semi-parametric partially linear models at effets fixes, refer to Baltagi and Li (2002).

Table 4. Estimates with CO2 emissions

Variables	FE	RE	OLS	SEMI-PARA
lnE	0.165***	0.151***	0.0301*	0.105***
	(0.0243)	(0.0233)	(0.0162)	(0.0366)
lnPIB	0.622	0.774	2.940***	–
	(0.642)	(0.631)	(0.875)	–
lnPIB2	0.0202	0.0110	−0.139**	–
	(0.0445)	(0.0439)	(0.0635)	–
lnindustry	0.0669	0.0638	−0.0910	0.124**
	(0.0486)	(0.0483)	(0.0813)	(0.0528)
lnservice	−0.0430	−0.0428	0.161	0.119*
	(0.0671)	(0.0667)	(0.102)	(0.0649)
Constant	−8.361***	−8.822***	−15.51***	–
	(2.191)	(2.151)	(2.870)	–
Observations	339	339	339	325
R-squared	0.628	–	0.695	0.137
Number of Id	14	14	–	–

*Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses.*

they are only significant in the semi-parametric estimates. Indeed, this implies that industrialization favors CO2 emissions and thus contributes to environmental degradation (Table 4).

Effects of income and income square on the CO2 emission were done with the OLS model. Then, the nature of the income-CO2 emission link was tested in the semi-parametric model by analyzing the graph describing the shape of the relationship between these two variables (Figure 1). Two observations can be made.

First, OLS estimation shows that income is positive and significant at the 1% threshold, and its quadratic term is negative and significant at the 5% threshold only (Table 4). Thus, the income-CO2 emission relationship in the ECOWAS zone follows a positive relationship, indicating that higher-income contributes to environmental quality degradation. Moreover, this result also confirms the verification of the Kuznets environmental curve in ECOWAS. These results confirm those of Ogundipe et al. (2014) for the lower-middle-income countries. Indeed, five of the main ECOWAS countries (Nigeria, Ghana,

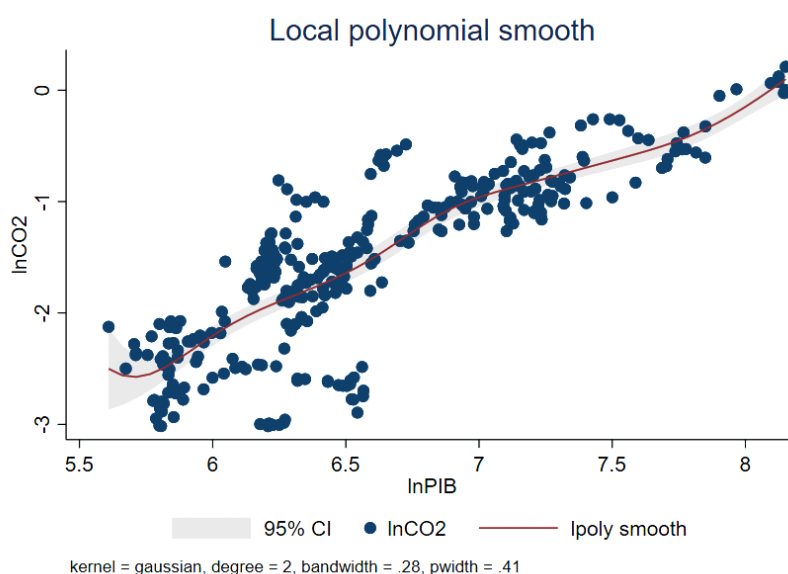**Figure 1.** Partial adjustment of the income-CO2 emission relationship

Table 5. Estimate with N02 emissions

Variables	FE	RE	OLS	SEMI-PARA
lnE	0.127***	0.142***	0.684***	0.0326
	(0.0352)	(0.0350)	(0.0444)	(0.0524)
lnPIB	2.041**	1.915**	7.441***	–
	(0.920)	(0.922)	(2.377)	–
lnPIB2	−0.0988	−0.0920	−0.550***	–
	(0.0637)	(0.0638)	(0.172)	–
lnindustry	0.0510	0.0481	−0.892***	−0.118
	(0.0704)	(0.0707)	(0.224)	(0.0756)
lnservice	0.485***	0.481***	−0.517*	−0.0411
	(0.0970)	(0.0975)	(0.281)	(0.0930)
Constant	−4.918	−4.496	−20.26***	–
	(3.144)	(3.167)	(7.794)	–
Observations	340	340	340	326
R-squared	0.375	–	0.514	0.068
Number of Id	14	14	–	–

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses.

Côte d'Ivoire, Senegal, and Cape Verde) are classified as lower-middle-income countries. The threshold for the reversal of the environmental curve is equal to $e^{(−2.94/2(−0.139))} = 39,165.03$ USD. This threshold, therefore, refers to the real GDP per capita equivalent to the maximum carbon dioxide emission value. It is only from this threshold that any increase in GDP would reduce CO2 emissions into the atmosphere. ECOWAS economies are, therefore, currently in the upward phase of the Environmental Kuznets Curve, since the level of their average real GDP per capita is USD 883.

Secondly, concerning the semi-parametric estimation technique, the curve in Figure 1 shows the absence of a U-inverted relationship contrary to the estimation with OLS model. The semi-parametric estimation fails to validate the EKC hypothesis leading to mixed results depending on the estimation technique. Not surprisingly, these results confirm the work of Stern (2004) and Effiong and Oisaozoje (2016), who conclude whether or not the EKC hypothesis is verified depends on the estimation techniques used.

3.2. Modelling using NO2 emissions as a measure of environmental degradation

Table 5 presents, as previously, the results of the estimates of the linear fixed-effect and semi-parametric models using the nitrogen dioxide (NO2) emission variable. The variables of energy consumption and value-added of the industrial sector are significant at the 1% threshold with a positive and negative sign. Energy consumption contributes more to nitrogen dioxide emissions and harms the environment. As for the verification of the EKC hypothesis, the OLS model shows that it is well verified in the context of nitrogen dioxide. The GDP per capita threshold corresponding to the maximum emission is set at $e^{(−7.441/2(−0.550))} = 866.57$ USD and above this threshold, any increase in per capita income translates into a reduction in the level of nitrogen dioxide emissions. The average value of ECOWAS per capita GDP (USD 883) being above this threshold, ECOWAS is in the decreasing phase of the EKC curve. Semi-parametric modeling also confirms the existence of this EKC relationship in the ECOWAS zone. Indeed, starting from no functional form between NO2 emission and GDP, the method suggests an inverted U-shape between nitrogen dioxide emission and GDP per capita (Figure 2). From these two analyses, it emerges that the parametric and semi-parametric methods converge on the validation of the EKC hypothesis in the ECOWAS region by considering nitrogen dioxide to measure environmental pollution.

3.3. Modelling using methane emission as a measure of environmental degradation

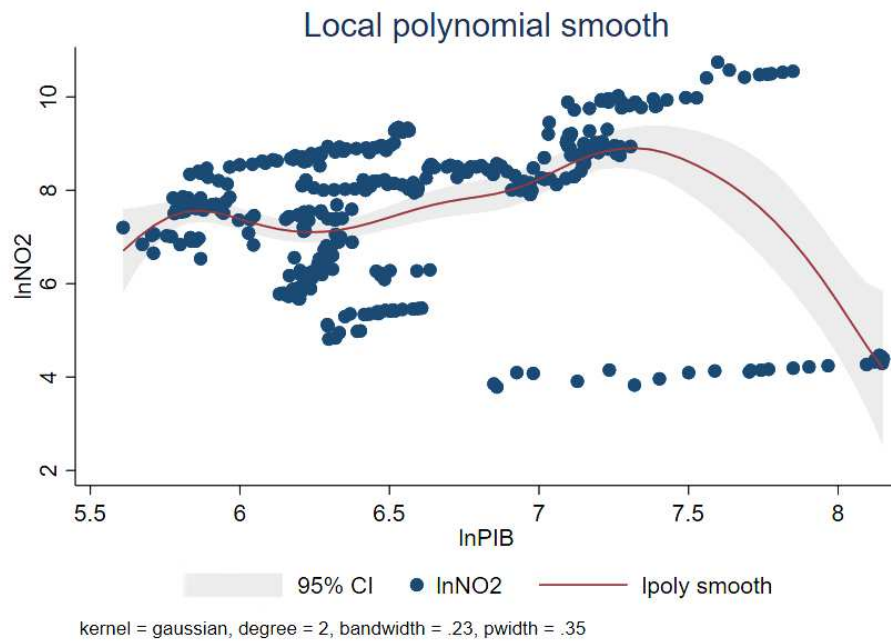The results of the methane emission estimates are reported in Table 6. The OLS model estimation

Figure 2. Partial adjustment of the income-NO2 emission relationship

showed that all variables are significant at the 5% threshold. Energy consumption and sectoral added values were found to be substantial and of positive sign. Thus, an increase in energy consumption and an increase in industrial activity and services contribute to a rise in methane emissions. The real GDP per capita and its quadratic term proved

significant with a positive and negative sign, verifying the EKC hypothesis. The threshold of GDP per capita equivalent to the maximum methane emission in the ECOWAS zone is $e^{(-3.257/2(-0.307))} = 199.95$ USD and indicates that the ECOWAS countries are on average in the decreasing phase of the Environmental Kuznets Curve.

Table 6. Estimate with methane emissions

Variables	FE	RE	OLS	SEMI-PARA
lnE	0.160***	0.207***	0.806***	0.0250
	(0.0323)	(0.0328)	(0.0288)	(0.0351)
lnPIB	3.005***	2.572***	3.253**	–
	(0.844)	(0.874)	(1.542)	–
lnPIB2	−0.175***	−0.151**	−0.307***	–
	(0.0584)	(0.0606)	(0.112)	–
lnindustry	0.0379	0.0462	0.771***	−0.0118
	(0.0646)	(0.0673)	(0.145)	(0.0507)
lnservice	0.180**	0.186**	0.624***	0.0330
	(0.0890)	(0.0929)	(0.182)	(0.0624)
Constant	−6.228**	−4.952*	−12.97**	–
	(2.885)	(2.985)	(5.056)	–
Observations	340	340	340	326
R-squared	0.366	–	0.777	0.037
Number of Id	14	14	–	–

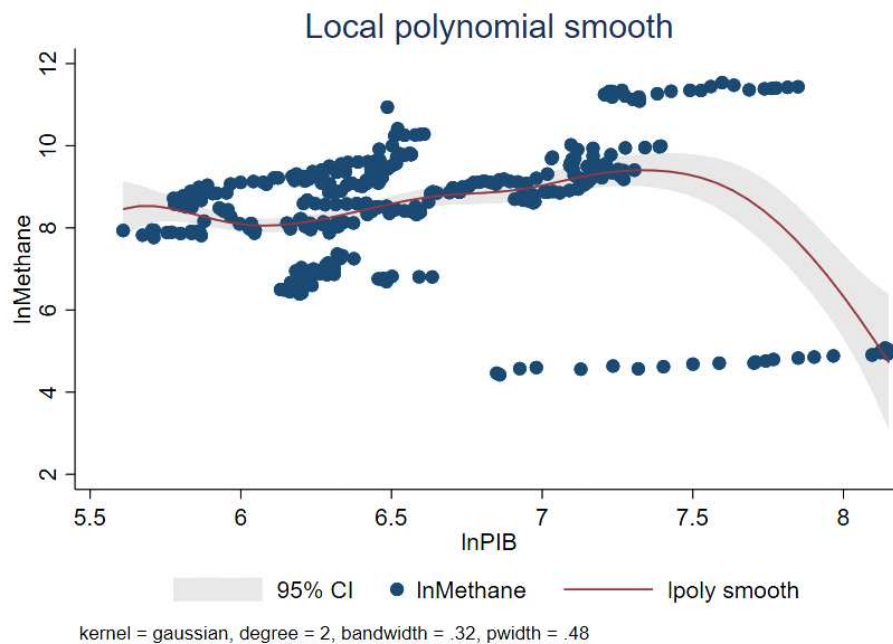*Note:* *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses.

Figure 3. Partial adjustment of the income-methane emission relationship

The semi-parametric estimate does not establish a relationship between methane emission and energy consumption variables and sectoral added values. Still, it confirms, through Figure 3, the verification of the EKC hypothesis in the ECOWAS zone. Thus, parametric and semi-parametric methods make it possible to validate the EKC hypothesis in the ECOWAS zone when methane emissions are used as a measure of degradation of environmental quality.

CONCLUSION

This paper aims to revisit the Environmental Kuznets Curve (EKC) to determine the revenue-pollution relationship's functional form using a sample of 14 ECOWAS member states over the period 1980–2014. The paper approaches income by GDP per capita and uses three indicators as proxies for pollution measurement: CO2, NO2, and methane emissions in parametric and semi-parametric modeling.

It emerges that for ECOWAS, the Kuznets environmental curve's hypothesis is confirmed if methane and nitrogen dioxide are used as degradation of the quality of the environment independently of the adoption of parametric or semi-parametric modeling. These results are consistent with those of Effiong and Oisaozoje (2016) and Keho (2017). However, with carbon dioxide as an indicator for measuring environmental pollution, the results are contradictory depending on whether the modeling is parametric or semi-parametric. The EKC curve is verified in parametric modeling and invalidated in semi-parametric modeling.

These results require awareness of the need to reduce CO2 emissions, which will continue to grow without clean production techniques. The ECOWAS Commission should promote measures among States and citizens of the Community to reduce CO2 emissions and preserve the ozone layer. These measures could concern the promotion of alternative or renewable energy sources such as solar, wind, and geothermal energy. Other actions could include combating deforestation to increase the absorption of CO2 released into the atmosphere.

AUTHOR CONTRIBUTIONS

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REFERENCES

1. Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review, 91*(4), 877-908. https://doi.org/10.1257/aer.91.4.877

2. Azomahou, T., Laisney, F., & Nguyen Van, P. (2006). Economic development and CO2 emissions: A non-parametric panel approach. *Journal of Public Economics, 90*(6-7), 1347-1363. https://doi.org/10.1016/j.jpubeco.2005.09.005

3. Baltagi, B. H., & Li, Q. (2002). On instrumental variable estimation of semiparametric dynamic panel data models. *Economics Letters, 76*(1), 1-9. https://doi.org/10.1016/S0165-1765(02)00025-3

4. Bertinelli, L., & Strobl, E. (2005). The Environmental Kuznets Curve semi-parametrically revisited. *Economics Letters, 88*(3), 350-357. https://doi.org/10.1016/j.econlet.2005.03.004

5. Chen, L., & Chen, S. (2015). The Estimation of Environmental Kuznets Curve in China: Non-parametric Panel Approach. *Computational Economics, 46,* 405-420. https://doi.org/10.1007/s10614-015-9486-7

6. Copeland, B. R., & Taylor, M. S. (1995). Trade and transboundary pollution. *American Economic Review, 85*(4), 716-737. Retrieved from https://www.jstor.org/stable/2118228

7. Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America.* https://doi.org/10.1073/pnas.94.1.175

8. Dinda, S. (2004). Environmental Kuznets Curve hypothesis: A survey. *Ecological Economics, 49*(4), 431-455. https://doi.org/10.1016/j.ecolecon.2004.02.011

9. Dinda, S., Coondoo, D., & Pal, M. (2000). Air quality and economic growth: An empirical study. *Ecological Economics, 34*(3), 409-423. https://doi.org/10.1016/S0921-8009(00)00179-8

10. Effiong, E., & Oisaozoje, A. (2016). *Let the Data Speak: Revisiting the Environmental Kuznets Curve in Africa* (MPRA Paper No. 73163). Retrieved from https://mpra.ub.uni-muenchen.de/73163/1/MPRA_paper_73163.pdf

11. Ehrlich, P. R., & Holdren, J. P. (1971). Impact of population growth. *Science, 171*(3977), 1212-1217. https://doi.org/10.1126/science.171.3977.1212

12. Grossman, G., & Krueger, A. (1991). *Environmental Impacts of a North American Free Trade Agreement* (NBER Working Paper No. 3914). https://doi.org/10.3386/w3914

13. Grossman, G., & Krueger, A. (1995). Economic growth and the environment. *Quarterly Journal of Economics, 110*(2), 353-377. https://doi.org/10.2307/2118443

14. Holtz-Eakin, D., & Selden, T. M. (1995). Stoking the fires? CO2 emissions and economic growth. *Journal of Public Economics, 57*(1), 85-101. https://doi.org/10.1016/0047-2727(94)01449-X

15. Keho, Y. (2017). Revisiting the income, energy consumption and carbon emissions nexus: New evidence from quantile regression for different country groups. *International Journal of Energy Economics and Policy, 7*(3), 356-363. Retrieved from https://www.econjournals.com/index.php/ijeep/article/view/4772

16. Kijima, M., Nishide, K., & Ohyama, A. (2010). Economic models for the environmental Kuznets curve: A survey. *Journal of Economic Dynamics and Control, 34*(7), 1187-1201. https://doi.org/10.1016/j.jedc.2010.03.010

17. Kuznets, S. (1955). Economic Growth and Income Inequality Simon. *American Economic Review,*

45(1), 1-28. Retrieved from https://assets.aeaweb.org/asset-server/files/9438.pdf

18. Lamla, M. J. (2009). Long-run determinants of pollution: A robustness analysis. *Ecological Economics, 69*(1), 135-144. https://doi.org/10.1016/j.ecolecon.2009.08.002

19. Liddle, B. (2001). Free trade and the environment-development system. *Ecological Economics, 39*(1), 21-36. https://doi.org/10.1016/S0921-8009(01)00215-4

20. Luzzati, T., & Orsini, M. (2009). Investigating the energy-environmental Kuznets curve. *Energy, 34*(3), 291-300. https://doi.org/10.1016/j.energy.2008.07.006

21. N'zué, F. F. (2018). the Environment and Growth Nexus: an Empirical Examination of the Environmental Kuznets Curve Hypothesisin Cote D'Ivoire. *International Journal of Development Research, 8*(9), 22846-22854. Retrieved from https://www.journalijdr.com/sites/default/files/issue-pdf/14100.pdf

22. ND-GAIN Country Index. (2018). *Côte d'Ivoire.* Retrieved from https://gain-new.crc.nd.edu/country/c-te-d-ivoire

23. Nguyen Van, P., & Azomahou, T. (2007). Nonlinearities and heterogeneity in environmental quality: An empirical analysis of deforestation. *Journal of Development Economics, 84*(1), 291-309. https://doi.org/10.1016/j.jdeveco.2005.10.004

24. Ogundipe, A. A., Alege, P. O., & Ogundipe, O. M. (2014). Income Heterogeneity and Environmental Kuznets Curve in Africa. *Journal of Sustainable Development, 7*(4), 165-180. https://doi.org/10.5539/jsd.v7n4p165

25. Osabuohien, E. S., Efobi, U. R., & Gitau, C. M. W. (2014). Beyond the Environmental Kuznets Curve in Africa: Evidence from Panel Cointegration. *Journal of Environmental Policy & Planning, 16*(4), 517-538. https://doi.org/10.1080/1523908X.2013.867802

26. Rosado, A. J. A. (2017). Economic growth, CO2 emissions and electric consumption: Is there an environmental Kuznets curve? An empirical study for North America countries. *International Journal of Energy Economics and Policy*, 7(2), 65-71. Retrieved from https://www.econjournals.com/index.php/ijeep/article/view/4068

27. Shahbaz, M., Ozturk, I., Afza, T., & Ali, A. (2013). Revisiting the environmental Kuznets curve in a global economy. *Renewable and Sustainable Energy Reviews, 25,* 494-502. https://doi.org/10.1016/j.rser.2013.05.021

28. Stern, D. I. (2004). Environmental Kuznets Curve. In *Encyclopedia of Energy* (pp. 517-525). https://doi.org/10.1016/b0-12-176480-x/00454-x

29. Wang, Y., Han, R., & Kubota, J. (2016). Is there an Environmental Kuznets Curve for SO2 emissions? A semi-parametric panel data analysis for China. In *Renewable and Sustainable Energy Reviews, 54,* 1182-1188. https://doi.org/10.1016/j.rser.2015.10.143

30. WDI. (2020). *World Development Indicators.* Retrieved from https://databank.worldbank.org/reports.aspx?source=world-development-indicators

31. York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics, 46(*3), 351-365. https://doi.org/10.1016/S0921-8009(03)00188-5

32. Yusuf, A. M., Abubakar, A. B., & Mamman, S. O. (2020). Relationship between greenhouse gas emission, energy consumption, and economic growth: evidence from some selected oil-producing African countries. *Environmental Science and Pollution Research, 27*(13), 15815-15823. https://doi.org/10.1007/s11356-020-08065-z