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Economic growth and pollution in the ECOWAS region: An application of the PSTR model

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Abstract: The destruction of the ozone layer through the release of greenhouse gases (GHG) into the atmosphere, leading to global warming, is one of the most serious environmental threats posed by anthropic activities. The aim of this article is to analyze the relationship between economic growth and environmental pollution in the countries of the Economic Community of West African States (ECOWAS), using the Kuznets Environmental Curve (KEC) and calculating decoupling indices. The econometric estimates are based on the Panel Smooth Threshold Regression (PSTR) model and cylindrical panel data covering the period from 1996 to 2021. Analysis of the decoupling indices reveals that no ECOWAS country is in a situation of recoupling, either from one period to the next, or over the entire study period. The estimation results indicate a non-linear relationship between the economic development indicator and the environmental indicator, and a threshold at which energy consumption, population density, Foreign Direct Investment (FDI) and trade openness significantly increase carbon dioxide (CO_2) emissions in ECOWAS countries. These results suggest that economic growth objectives should be accompanied by adaptation measures, and that attention should be paid to the quality of FDI and to the migration of industries.

Keywords: Economic growth; Decoupling; PSTR; Pollution; Global warming.
JEL Classification : Q56 - O44 - O13.

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1. Introduction

Environmental issues and their integration have become major concerns of our time. Economic development policies have led to significant degradation of the planet's environment through overexploitation of natural resources and pollution (Van Duysen and Jumel, 2008: 41). Since the United Nations Framework Convention on Climate Change (UNFCCC) came into force on March 21, 1994, the international community has been looking for ways to control the phenomenon, reduce its adverse effects and develop adaptation strategies for the most vulnerable populations. According to the International Energy Agency (IEA, 2014), global energy production for consumption comes from fossil fuels and represented 11.2 Gtoe[1] in 2004, with 3.95 Gtoe for global oil production, 2.8 Gtoe for coal, 2.4 Gtoe for natural gas, 1.2 Gtoe for biomass and renewables and 0.7 Gtoe for nuclear. The concept of sustainable development formalized by the Brundtland Report (1987) requires every nation to reflect on the interactions between Man, Society and Nature. The importance attached to global warming has changed the logic of environmental protection in public debate, since Greenhouse Gas (GHG) emissions in one region affect the whole planet. From an economic point of view, the climate is considered a "global public good" (Kindleberger, 1986), which dilutes the responsibilities of each emitting country.

The countries of the Economic Community of West African States (ECOWAS) are not immune to these issues. The economies of the ECOWAS states are essentially based on natural resources, including forests, wildlife, grazing land, water and farmland. These resources are exploited by populations that are growing at an exponential rate. This situation creates conflicts and deadlocks in the management of these resources and generates effects and phenomena that degrade the environment. These problems are compounded by GHG emissions, including carbon dioxide (CO_2). The poor quality of the environment has a negative impact on people's living conditions.

Admittedly, some work has introduced the environmental issue into economic analysis, based on the Kuznets Environmental Curve (KEC). But the results of this work are mixed. Some corroborate the CEK (Holtz-Eakin and Selden, 1995; Shahbaz and al., 2014; Wang and al., 2022); others do not (Parikh and Shukla, 1995; Kuo and al., 2014; Shahbaz and al., 2018).

The divergence in results can be explained by the nature of the data, the variables and the methodology used. Indeed, the results obtained from time-series data would be biased if the number of observations is low. Similarly, using two variables to explore the link between economic growth and pollution would lead to partial results, as certain macroeconomic variables could play an important role in this relationship. From this perspective, what is the relationship between economic growth and environmental quality in ECOWAS countries? This article is in line with this theme and adds to the literature on ECOWAS countries.

By responding to the research question and the limitations of previous work, the article contributes to the literature on the subject on several points: the first contribution is that few studies have tackled this theme in this geographical area; the second contribution is the use of panel data, which provides reliable results ; the third contribution results from the integration of other variables such as total energy consumption, population density, share of the industrial sector, trade openness and foreign direct investment; the fourth contribution is methodological and consists in using decoupling indices and the Panel Smooth Threshold Regression (PSTR) model, unlike previous studies which used the AutoRegressive Distributed Lags (ARDL), Vector AutoRegressive (VAR) and Vector Error Correction Model (VECM) models.

[1] Gtep: unit of measurement for energy. 1 Gtep = 10^3 Mtep = 10^6 Ktep = 10^9 toe; with toe the tonne of oil equivalent.

The rest of the paper is organized as follows. Section 2 presents the literature review, followed by the analytical methodology in section 3. The fourth section describes the data and variables used in the study. Results and discussion are reported in section 5. Finally, the last section concludes.

2. Literature Review

This section encompasses previous theoretical and empirical contributions.

2.1 Theoretical Foundations

This subsection focuses on the theoretical perspectives regarding the relationship between economic growth and the environment.

2.1.1 Natural Capital in Economic Thought

Three major schools of thought have examined the theoretical foundations of the market economy by exploring the relationship between economics and the environment: classical economics, neoclassical economics, and institutional economics.

The early theories of economic growth (Smith, 1776; Malthus, 1798; Ricardo, 1817) emphasized the importance of capital accumulation in the growth process. For Smith, the division of labor enhances skill specialization and eliminates inefficiencies. Ricardo and Malthus viewed capital accumulation as the primary driver of growth. The classical economists identified three factors of production: land, which includes natural resources, capital, and labor. By linking economic growth to environmental considerations, the Malthusian and Ricardian theories focused on how the fixed supply of land would constrain economic growth, leading to its eventual stagnation. Over time, production would increase at a diminishing rate per additional unit of capital and labor. The competition for the best land would drive up rents, reducing profits until only landlords could earn rents, leaving no profits for capitalists and halting investment. Wages would stabilize at subsistence levels, population growth would cease, and the economy would reach a stationary state of stagnation and misery. Mill (1848) introduced ethical dimensions into political economy, advocating state intervention and viewing the environment as both a productive source and a provider of well-being.

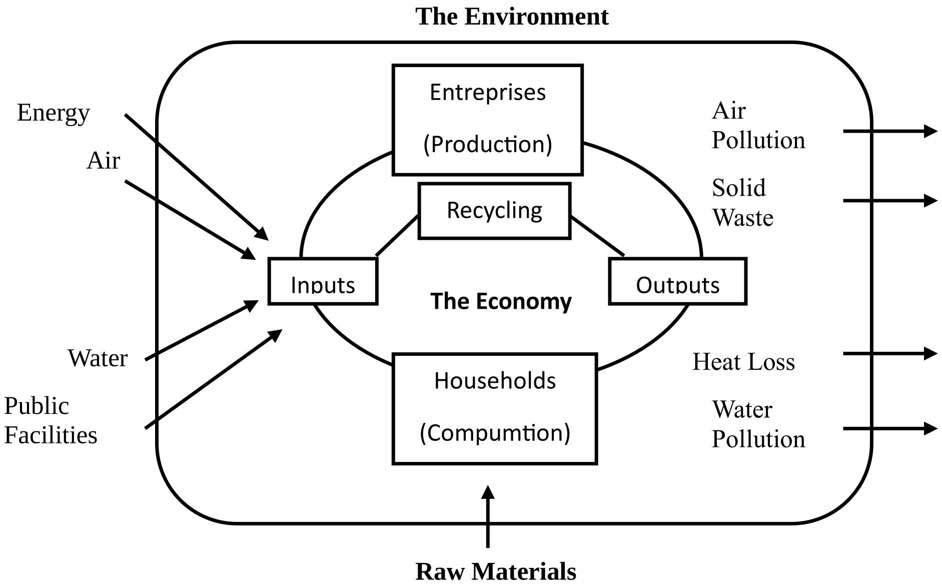
Neoclassical theory reinforced classical conclusions by redefining foundational economic assumptions, such as introducing a new theory of value based on utility. Walras (1875), in his studies, explored the three dimensions of sustainable development. Jevons (1878), a pioneer of natural resource theory, focused on coal and demonstrated that increasing the extraction of non-renewable natural resources leads to price increases that can support economic growth. The oil shocks of the 1970s, however, reignited concerns about natural resources. The relationship between the economy and the environment was reexamined, particularly in light of the risk of resource depletion. In line with Malthus's (1798) reflections, the Club of Rome published a report titled Limits to Growth, which argued that continued economic growth would lead to medium-term population decline due to soil degradation, fossil fuel depletion, and pollution. In 1987, aiming to bridge the development gap for the Global South while preserving the environment, the United Nations established the World Commission on Environment and Development (WCED), which produced the Our Common Future report.

Institutional economics views the market as a social construct shaped by human activity, with needs organized hierarchically, similar to Maslow's (1943) pyramid structure. This school of thought emphasizes the connection between economics and ethics, drawing inspiration from Mill (1848). Humans experience physiological needs, which are complemented by material needs such as security and protection. This perspective calls for a reorientation of value systems, stressing the necessity of ethical considerations to guide economic action.

2.1.2 Economic Assessment and Externalities of Air Pollution

Economically, the environment is a composite asset that provides the economy with raw materials transformed into consumer goods through the production process, as well as the energy required to fuel this transformation (Figure 1). At the end of the chain, these raw materials and energy are discharged back into the environment in the form of waste.

Figure 1: Economic System and the Environment



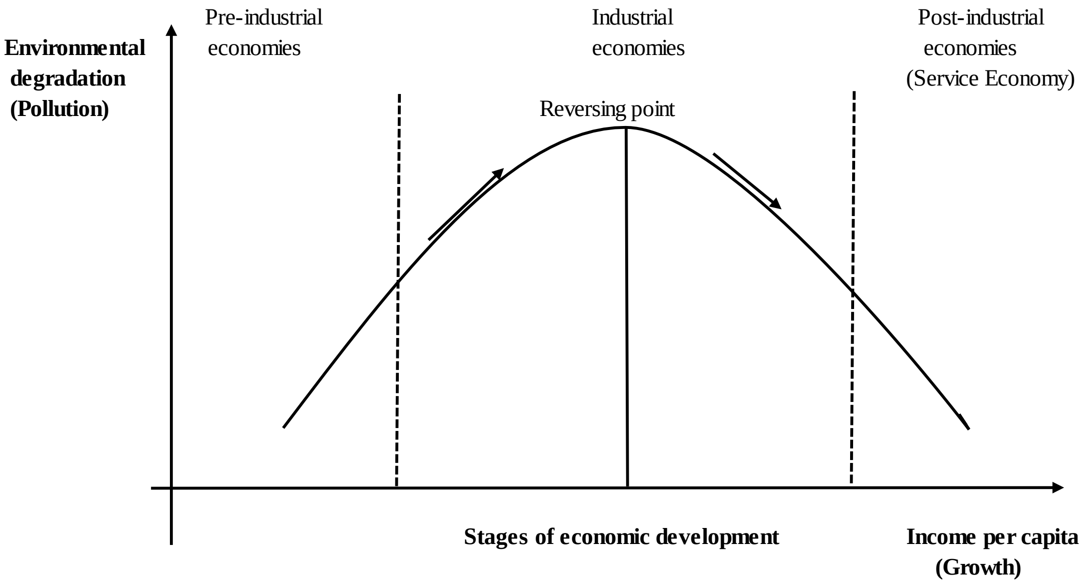
Source: Adapted from Tietenberg and Lewis (2013: 24).

The externalities of air pollution on the environment are felt at various levels: on buildings and monuments, vegetation, and human health. For buildings and monuments, these externalities manifest as corrosion caused by sulfur compounds, blackening and encrustation from dust or particles generated by the combustion of fossil fuels, often in combination with humidity and microorganisms. For vegetation, the impacts include reduced growth, sometimes leading to poor agricultural yields. Other negative effects include acid rain, which depletes soil nutrients and leads to forest decline. Air pollution also has harmful effects on human health. According to the World Health Organization (WHO), it ranks as the 13th leading cause of mortality globally. In developing countries, where regulatory standards are less stringent and evaluation technologies remain outdated, the WHO estimates that air pollution accounts for approximately 2 million premature deaths annually, including 82,000 in Sub-Saharan Africa (WHO, 2008).

2.1.3 Analysis of the Environmental Kuznets Curve

The Environmental Kuznets Curve (EKC) illustrates a shift in the positive relationship between environmental degradation and income per capita, transitioning to a negative relationship beyond a certain threshold.

Figure 2: Different Phases of the Environmental Kuznets Curve



Source: Adapted from Panayotou (2003:3).

Figure 2 shows three major columns in which countries can be classified based on the type of relationship between income per capita and per capita pollutant emissions: the left column, the central column, and the right column. The first column corresponds to pre-industrial nations, where the relationship between income per capita and pollutant emissions is positive. The second column pertains to industrial economies. In these countries, the consumption of natural resources, particularly energy, is higher; environmental degradation reaches its peak, and income per capita improves this represents the turning point. In the third column, the increase in GDP per capita is a decreasing function of per capita CO_2 emissions. This situation characterizes post-industrial economies, which, having reached a high level of development, shift toward less polluting technologies and focus on service-oriented activities.

2.2 Empirical Review

This subsection presents, on one hand, studies confirming the Environmental Kuznets Curve and, on the other hand, those that do not.

2.2.1 Summary of Studies Confirming the Environmental Kuznets Curve

The 1990s marked the beginning of empirical studies testing the effects of economic growth on environmental indicators (CO, CO_2, SO_2, NOx, deforestation, municipal waste, particulate matter, etc.). In testing the Environmental Kuznets Curve (EKC) hypothesis for air and water pollution, with turning points set at \$5,000 and \$8,000 respectively, Grossman and Krueger (1991, 1995) obtained an inverted "U"-shaped curve. Shafik and Bandyopadhyay (1992), studying a sample of 149 countries from 1960 to 1990, found an inverted "U"-shaped curve for SO_2, deforestation, and CO_2 emissions, with turning points at \$3,000, \$2,000, and \$4,000, respectively. Holtz-Eakin and Selden (1995) studied the link between economic development and CO_2 emissions and concluded that as GDP increases, the marginal propensity to emit CO_2 decreases.

As research evolved, various variables were introduced into the analysis of the determinants of environmental quality. For instance, Zhu and al. (2012), using a semi-parametric model and observing variations in 20 emerging countries, confirmed a non-linear, inverted "U"-shaped relationship between urbanization and CO_2 emissions. Shahbaz and Bandyopadhyay (2014) studied the effects of economic growth on CO_2 emissions, incorporating explanatory variables such as electricity consumption, urbanization, income per capita, and exports, and found an inverted "U"-shaped relationship. Using a PSTR (Panel Smooth Threshold Regression) model on a panel of 146 countries covering the period 1990–2016, Khan and Eggoh (2021) demonstrated that trade openness increases CO_2 emissions and attenuates the positive effect of income in the EKC. In this context, the work of Wang and al. (2022), employing various methodological approaches, validated the EKC hypothesis.

2.2.2 Summary of Studies Not Confirming the Environmental Kuznets Curve

Other researchers have tested the EKC hypothesis and did not find the inverted "U"-shaped curve. The diversity of results can be attributed to factors such as the level of development of the countries, the study period, the degree of homogeneity of the sample, the control variables, and the cubic or quadratic form of the EKC model. For example, Parikh and Shukla (1995), in exploring the effects of urbanization on energy consumption and carbon emissions in developing nations, found that a 10% increase in the urban population led to a 4.7% increase in per capita total energy consumption and a 0.3% increase in per capita CO_2 emissions.

In a study on South Africa, Menyah and Wolde-Rufael (2010) demonstrated a unidirectional causal relationship from pollutant emissions to economic growth, and from energy consumption to CO_2 emissions, contrasting with Ozturk and Acaravci (2010), who, using a distributed lag cointegration model, found no causal relationship between energy consumption and carbon emissions. In Saudi Arabia, the results of Alkhathlan and Javid (2013) using the ARDL approach indicated a short-term and long-term relationship between energy consumption, economic growth, and CO_2 emissions. In their causality analysis, Kuo and al. (2014) showed that, in Hong Kong, there is a unidirectional causal relationship between CO_2 emissions and energy consumption, and between economic growth and CO_2 emissions.

Despite the existence of a long-term relationship between economic growth and environmental quality, Zhang and al. (2017) applied three methods AutoRegressive Distributed Lags (ARDL), Vector AutoRegressive (VAR), and Vector Error Correction Model (VECM) for China during the period 1978–2016 and found divergent results depending on the method used. Shahbaz and al. (2018) found that economic growth is positively linked to environmental quality, while financial development increases CO_2 emissions. Fongnikin and Lanha (2020) used the "Stochastic Impacts by Regression on Population, Affluence and Technology" (STIRPAT) model to study the factors driving environmental degradation in four West African Economic and Monetary Union (WAEMU) countries from 1974 to 2014. Using the "Fully Modified Ordinary Least Squares" (FMOLS) and "Dynamic Ordinary Least Squares" (DOLS) methods, they concluded that population density does not influence CO_2 emissions, while GDP per capita, agricultural practices, and urbanization have a positive impact on CO_2 emissions.

3. Methodology of analysis

This section is structured around two key points: the formalization of the model and the tests.

3.1 Specification of the PSTR model

To examine the relationship between economic growth and CO_2 emissions, this study uses the PSTR (Panel Smooth Threshold Regression) model developed by González and al. (2005). The PSTR model is a generalization of the PTR model by Hansen (1999). Unlike the PTR model, which suggests a sudden transition between two extreme regimes located on the left and right of a threshold, the PSTR model models phenomena where the transition from one regime to another occurs gradually (smooth transition). This model allows for accounting for the heterogeneity in the relationship between economic growth and pollutant emissions. The functional form of the model is:

$$CO_2 = f(GDPh, ENG, DNS, IND, OUV, FDI) \tag{1}$$

In its PSTR from, equation (1) is expressed as follows:

$$lnCO2_{it} = \mu_i + \beta_0 lnGDPh_{it} + \beta_1 lnGDPh_{it} g(lnGDPh_{it-1};\ \gamma, c) + \alpha_0' Z_{it} + \varepsilon_{it} \tag{2}$$

with i = 1,2,…,N representing the number of individuals and t = 1,2,…,T denoting the study period. The dependent variable CO_2 represents carbon dioxide emissions per capita. The variable of interest is the Gross Domestic Product per capita (GDPh), which is also used as the threshold variable in this study (Van Dijk and al., 2002); μ_i denotes country-specific fixed effects. β_0 and β_1 represent the parameter vectors of the linear and nonlinear models, respectively. Z_{it} is a k dimensional vector of control variables, including total energy consumption, population density, the share of the industrial sector, trade openness, and Foreign Direct Investment (FDI). The transition function $g(lnGDPh_{it-1};\ \gamma, c)$ is continuous and integrable over [0,1]. This function depends on the threshold variable $lnGDPh_{it-1}$, the smoothing parameter (γ) and a vector of threshold parameters (c). The error term ε_{it} independently and identically distributed i.i.d. $(0,\sigma^2)$. Drawing inspiration from Teräsvirta (1994), and González and al. (2005), this article considers a logistic transition function of order m, defined as follows:

$$g(lnGDPh_{it-1};\ \gamma, c) = \left[1 + \exp\left(-\gamma \pi_{j=1}^{m} (lnGDPh_{it-1} - c_j)\right)\right]^1 \tag{3}$$

$$\text{where } \gamma > 0,\ c_1 \leq c_2 \leq \ldots \leq c_m$$

$c = (c_1, \ldots, c_m)$ represents a vector grouping the threshold parameters, and γ is a smoothing parameter describing the transition from one regime to another, where $\gamma > 0$. The order of the logistic transition function directly influences the transitional dynamics between extreme regimes. According to González and al. (2005), it is generally sufficient to consider m = 1 or m =2. The case m = 1 corresponds to a logistic PSTR specification, whereas m = 2 corresponds to a quadratic logistic PSTR model. If $\gamma \to \infty$, the transition becomes abrupt between regimes, and the transition function $g(lnGDPh_{it-1};\ \gamma, c)$ simplifies to $g(lnGDPh_{it-1};\ \gamma)$ reducing the PSTR model to a PTR model (Hansen, 1999). Conversely, when $\gamma \to 0$, the transition function $g(lnGDPh_{it-1};\ \gamma, c)$ remains constant, and the PSTR model reduces to a fixed-effects panel model. Finally, small and large values of $(lnGDPh_{it-1})$ correspond to the two extreme regimes. The elasticity of CO_2 emissions concerning economic growth for country I at time t is expressed as follows:

$$\frac{\partial lnCO_{2it}}{\partial lnGDP_{it}} = \beta_0 + \beta_1 g(lnGDPh_{it-1};\ \gamma, c) \tag{4}$$

The elasticity of CO_2 emissions with respect to economic growth can be considered as a weighted average of the parameters β_0 and β_1, and as such, it allows for a more precise analysis of the impact of economic growth on pollution.

3.2 Testing Procedure

Before estimating the PSTR model, some tests are required: the linearity test and the "no remaining linearity" test. The linearity test aims to determine whether the relationship between the dependent and independent variables can be represented by a regime-switching model or not. This involves testing the null hypothesis $H_0: \gamma = 0$ ou $H_0: \beta_1 = 0$.

The test will be non-standard in both cases under the null hypothesis, as the PSTR model contains nuisance parameters that are undetermined. To address this, González and al. (2005) suggest following the same procedure proposed by Luukkonen and al. (1988) for Smooth Transition Autoregressive Regression (STAR) models, by replacing the transition function $g(\ln PIB_{it-1};\ \gamma, c)$ with its first-order Taylor expansion around the null hypothesis $H_0: \gamma = 0$ and testing an equivalent hypothesis in an auxiliary regression. For m regimes, the model (5) is as follows:

$$\ln CO_{2it} = \mu_i + \beta_0^* \ln GDPh_{it} + \beta_1^* \ln GDPh_{it} \ln GDPh_{it-1} + \ldots + \beta_m^* \ln GDPh_{it} \ln \beta_{it-m}^{m} + \varepsilon_{it}^* \qquad (5)$$

The β_i coefficients being proportional to the smoothing parameter γ of the transition function, the linearity test of the economic growth-pollution model with respect to the PSTR model boils down to testing:

$$\begin{cases} H_0: \beta_1 = 0 \\ H_1: \beta_1 \neq 0 \end{cases}$$

This hypothesis is tested using the Lagrange multiplier statistic. Let SCR_0 be the sum of squared residuals from a linear model with individual effects, and SCR_1 the sum of squared residuals from a nonlinear (PSTR) model with m regimes. The associated Fisher statistic is given by:

$$LM_F = \frac{(SCR_0 - SCR_1)/mK}{(SCR_0/(TN - N - mK)} \sim F(mK, TN - N - mK) \qquad (6)$$

With T representing the number of years, N the number of countries, and K the number of explanatory variables, the "no remaining linearity" test aims to determine the number of thresholds (or regimes) required to describe the data dynamics (Colletaz and Hurlin, 2006). Specifically, this involves testing the null hypothesis of a PSTR model with a single transition function (r = 1) against the alternative hypothesis of a PSTR model with at least two transition functions (r = 2).

4. Data and Definition of Variables

This section is dedicated to the descriptive analysis of the data and the definition of the variables.

4.1 Descriptive Analysis of the Data

The first subsection presents the data and descriptive statistics. The second analyzes the evolution of CO_2 between 1996 and 2021 by applying the concept of decoupling.

4.1.1 Data and Sources

Annual data from the World Bank database (World Development Indicators (WDI, 2023)) are used in this study. The data concerns the ECOWAS countries and spans the period 1996-2021, covering 26 years. Table 1 presents the descriptive statistics of the variables. Between 1996 and 2021, the average CO_2 emissions are 0.398 metric tons per capita. The minimum CO_2 value is 0.053 metric tons per capita, recorded in Niger in 2006, while the maximum value is 0.906, recorded for Nigeria in 1996. The average GDP per capita is 1076.279 US dollars, with a minimum value of 197.833 in Niger in 2000 and a maximum value of 3098.986 in 2014 for Nigeria. Energy consumption averages 402.216 kilotons of oil equivalent per capita (ktep/cap), with a maximum value of 799.630 (ktep/cap) in 2021 in Nigeria and a minimum value of 113.090 (ktep/cap) in Niger in 2011. Population density fluctuated from 1996 to 2021, ranging from 8.013 (in 1996 in Niger) to 228.738 (in 2021 in Nigeria), with an average of 89.044 during the study period. The value added by the industrial sector stabilized around the average of 21.330. The lowest level was 12.566 in 1998 in Benin, while the highest level was recorded in 1996 with 37.445 for Nigeria. Over the period, the trade openness rate stabilized around the annual average of 28.340. After reaching its lowest level in 2020 (8.176 for Nigeria), it continuously increased to 58.024 in 2000 for Ghana. The average FDI during the period was 2.407, with a minimum level of -2.545 in 2018 and a maximum value of 18.818 recorded in Togo in 2011.

Table 1. Descriptive Statistics

Variables	Observations	Mean	Standard-Error	Min.	Max.
CO_2 (MT/hbt)	182	0.398	0.198	0.053	0.906
GDP per capita (current US dollars)	182	1076.279	684.473	197.833	3098.986
ENG (ktep/per capita)	182	402.216	189.030	113.090	799.630
DNS (hbt/km^2)	182	89.044	50.748	8.013	228.738
IND (% GDP) *100	182	21.330	4.900	12.567	37.444
OUV (% GDP) *100	182	28.340	9.557	8.176	58.024
FDI (% GDP) *100	182	2.407	2.603	2.545	18.818

Note: MT = Metric Tons; hbt = Per Capita; ktep = Kilotonnes of Oil Equivalent.
Source: Autors, WDI (2023).

4.1.2 Multicollinearity Test

Multicollinearity leads to an increase in the estimated variance of certain coefficients when collinearity between the explanatory variables rises, causing instability in the coefficient estimators. Table 2 presents the results of this test.

Table 2. Multicollinearity Test for Different Variables

	lnCO2	lnGDPh	lnENG	lnDNS	lnIND	lnOUV	FDI
lnCO2	1.000						
lnGDPh	0.664	1.000					
lnENG	0.742	0.551	1.000				
lnDNS	0.760	0.555	0.763	1.000			
lnIND	0.333	0.233	0.083	0.237	1.000		
lnOUV	0.167	-0.153	0.041	0.254	-0.1725	1.000	
FDI	-0.070	0.034	-0.249	-0.063	0.139	0.315	1.000

Source : Autors, WDI (2023).

According to Gujarati (2003), multicollinearity is a concern when correlation coefficients exceed 0.8. As shown in Table 2, the correlations between the dependent variable and the independent variables are significant. In fact, GDP per capita is correlated with CO_2 emissions. However, this raises the issue of omitted variable bias. It is crucial to run regressions with control variables. In light of the table, it appears that the correlation between GDP per capita and the control variables is significant but relatively weak. The same holds true for the correlations between pairs of control variables.

4.1.3 Stationarity Tests

Different tests are used to check the stationarity of panel data. First-generation tests aim to test for the presence of unit roots while considering heterogeneity under the assumption of individual independence. These tests are then corrected by second-generation tests that account for potential inter-individual dependencies. In this study, we first test for the existence of inter-individual dependence (Table 3); then, we conduct first and second-generation tests based on the results obtained.

Table 3. Test of Inter-Individual Independence in the Case of Heterogeneous Panels (Pesaran, 2004)

Variables	Statistics	p-value
$lnCO_2$	3.990***	0.000
lnGDP per capita	21.630***	0.000
lnENG	11.190***	0.000
lnDNS	23.340***	0.000
lnIND	0.580	0.559
lnOUV	2.370**	0.018
FDI	1.460	0.145

Note : Significativity : *** 1 % ; ** 5 %. N = 7 ; T = 26 ; Obs = 182.
Source : Autors, WDI (2023).

The interdependence tests show that first-generation tests are sufficient for two variables (lnIND and IDE). The Pesaran (2004) test, presented in Table 3, allows us to reject the hypothesis of interdependence between the panel individuals for these variables. Second-generation tests (Table 4) are necessary to test the stationarity of the other variables in the model.

Table 4. Results of Panel Unit Root Tests

Tests	Variables						
	lnCO2	lnPIBh	lnENG	lnDNS	lnIND	lnOUV	IDE
IPS	-2.440*** 0.007	-1.796** 0.036	-2.742*** 0.003	-3.098*** 0.001	-	-2.402*** 0.008	-
LLC	-3.049*** 0.001	-2.568*** 0.005	-1 .812** 0.035	-7.882*** 0.000	-	-3.009*** 0.001	-
Pesaran	-	-	-	-	-1.328* 0.092	-	-1.964** 0.025
T	26	26	26	26	26	26	26
NT	182	182	182	182	182	182	182

Source : Autors, WDI (2023).

4.1.4 Decoupling: Concept (s) and calculation

A complementary analysis to descriptive statistics is "decoupling." The first definition of "decoupling" was provided in 2001 by the Organization for Economic Co-operation and Development (OECD) in its report titled "Environmental Strategy for the First Decade of the 21st Century." In this report, "decoupling" is defined as the break in the positive relationship between the production of economic goods and the harmful effects on the environment. The concept of decoupling suggests that domestic production can increase while environmental degradation can be controlled. There are two types of decoupling: "resource decoupling" and "impact decoupling." The first refers to the decoupling between resource use and economic growth, while the second refers to the decoupling between the environmental impact of resource use and economic growth.

Decoupling, whether resource or impact decoupling, can be either relative or absolute. It is relative when the amount of material used grows slower than a given economic index, and absolute when the amount of material used decreases while the economic index grows. Wang (2010) defined decoupling and its opposite, recoupling. According to the author, decoupling refers to the ratio of the variation in natural resource use (resource decoupling) or the variation in environmental pressure relative to the economic growth rate over a specific period. However, the present research refers to the OECD decoupling index (2002). Let ID denote this index; we have:

$$\mathrm{ID} = \frac{\left(\mathrm{EP}/_{\mathrm{DF}}\right)\text{end of the period}}{\left(\mathrm{EP}/_{\mathrm{DF}}\right)\text{debut of the period}}$$

where EP represents environmental pressure, measured by CO_2 emissions per capita, and DF represents output, measured by GDP per capita. Moreover, the Decoupling Index (ID) can take various values. Thus:
if $0 < ID < 1$ it indicates a situation of relative decoupling;
if $ID \geq 1$ it indicates a situation of absolute decoupling;
if $ID \leq 0$ it indicates a situation of recoupling
Table 5 summarizes the decoupling index between CO_2 and GDP for each country over six-year periods and the entire study period.

Table 5. Results of the decoupling index calculation (CO_2–GDP) over the period 1996-2021

Countries / Periods	1996-2001	2001-2006	2006-2011	2011-2016	2016-2021	1996-2021
Benin	1.155	1.039	0.881	1.311	0.768	1.066
Côte-d’Ivoire	1.723	0.584	0.740	1.1991	0.810	0.722
Ghana	1.981	0.356	0.717	0.958	0.930	0.451
Niger	1.079	0.576	1.019	1.262	0.753	0.603
Nigeria	0.702	0.273	0.624	1.168	0.999	0.139
Senegal	1.534	0.695	0.892	1.252	0.760	0.905
Togo	0.858	0.839	0.975	0.586	0.775	0.318

Source : Autors, WDI (2023).

It can be deduced from Table 5 that no country in ECOWAS is in a recoupling situation, neither from one period to another nor over the entire study period. CO_2 emissions have not grown faster than GDP per capita. Benin and Niger are in an absolute decoupling situation for almost all periods, including the entire study period. Côte d'Ivoire and Senegal are in a relative decoupling situation, except for the sub periods 1996-2001 and 2001-2016. Except for the period 1996-2001, Ghana is in a relative decoupling situation. Nigeria is in a relative decoupling situation except for the sub periods 2011-2016 and 2016-2023, while Togo is in a relative decoupling situation across all periods.

4.2 Definition of variables

The relationship between economic growth and environmental effects is difficult to test due to the lack of long-term data on environmental pollutants. As a result, studies tend to focus on variables such as CO_2 emissions and energy use, for which databases are available. The use of CO_2 is justified by the fact that this variable alone accounts for 75% of global warming. Additionally, its regulation has become a very important intergovernmental issue (Talukdar and Meisner, 2001).
CO_2 emissions are measured in metric tons per capita. Gross Domestic Product per capita (GDPh) is in current US dollars, capturing the effect of the level of development on the environment. According to the Environmental Kuznets Curve (EKC), as a country wealth increases, individuals prioritize environmental quality once their basic needs are met.

Energy consumption (ENG) is measured in kilotons of oil equivalent (ktep) per capita. Like capital and labor, energy is a factor of production and plays a significant role in the economic, social, political, and environmental aspects (IEA, 2014). It contributes to the creation of wealth and the well-being of populations. Energy consumption refers to the use of solid biomass, liquid biomass, biogas, coal, oil, shale oil, and natural gas products as energy sources. It is the second-largest source of greenhouse gas emissions globally.

Population density (DNS) is the number of people per square kilometer. It is an explanatory factor for environmental quality. As the population grows, the environmental quality deteriorates (Dinda, 2004). Population growth increases food demands, overexploitation, depletion of natural resources, and pollution emissions.

The industrial sector share (IND) is the percentage of total GDP. According to Liddle and Lung (2010), including the industrial sector in the economy would lead to a mis-specification of the model, as the share of the manufacturing sector in economic activity has declined in recent years, which is not the case for CO_2 emissions. Therefore, the value added by the industrial sector in GDP is an indicator of technological impact.

Trade openness (OUV) is measured by the sum of imports and exports relative to GDP. It affects environmental quality (Dinda, 2004). It has a dual effect: through an economies of scale effect, trade (exports) can accelerate the production of an economy, leading to more pollution. Through a composition and/or technical effect, developed nations (due to strong environmental regulation) may relocate polluting industries to poor economies with weak environmental regulation through foreign direct investment, which results in decreased pollution in rich nations.

Foreign Direct Investment (FDI) is expressed as a percentage of GDP. It contributes to capitalizing national assets, stimulating job creation, and improving productivity and economic competitiveness through imported technology and expertise (UNDP, 2003). The influence of FDI on environmental quality is explained by the "pollution haven" hypothesis or the "pollution halo" hypothesis. These two hypotheses argue that depending on the production activities and technology adopted by foreign companies, an increase in FDI may either increase (haven) or decrease (halo) pollution emissions in host nations (Solarin and al., 2017).

5. Results and discussion

This section presents and discusses the main results of the economic growth-pollution relationship obtained from a Panel Smooth Threshold Regression (PSTR) model proposed by González and al. (2005). In the specification, the variable that exhibits non-linearity (GDPh) is also used as the threshold variable in the transition function. The results are presented in three stages: first, the non-linearity tests; second, the determination of the number of regimes; and finally, the estimation of the PSTR model.

The testing procedure is as follows: initially, the linear model ($r = 0$) is tested against a non-linear model with one threshold ($r = 1$). If the null hypothesis is not rejected, the procedure stops. However, if the null hypothesis is rejected, the next step is to test the non-linear model with one threshold against a non-linear model with two thresholds ($r = 2$). Each test is performed with a first-order transition function ($m = 1$), followed by a second-order transition function ($m = 2$). It is also possible to test a model with three (3) transition functions, or even more, with higher-order transition functions ($m > 2$).

5.1 Results of linearity tests

The results of the non-linearity tests between economic growth and pollution using GDP per capita as the transition variable are presented in Table 6.

Table 6. Linearity tests

Test hypotheses	H_0 : linear model			
	H_1 : PSTR model with at least one threshold variable (r = 1)			
Order of function	m = 1		m = 2	
Wald Tests (LM) :	W = 37.490	pvalue = 0.000	W = 55.211	pvalue = 0.000
Fisher Tests (LMF) :	F = 8.821	pvalue = 0.000	F = 7.185	pvalue = 0.000

Source : Autors, WDI (2023).

The LM and LMF tests allow us to reject the null hypothesis of the linear model at a 1% significance level. We can state with a 1% risk of error that there is a nonlinear relationship between economic growth and the variables in the model, particularly CO_2 emissions.

5.2 Results tests ''no remaining linearity''

After the linearity tests, determining the optimal number of transition functions is necessary. This aims to determine the number of regimes that describe the dynamic relationship between economic growth and pollution. The two tests (LM, LMF) in Table 7 help to choose between a one-threshold transition function and a two-threshold transition function.

Table 7. Determining the Optimal Number of Thresholds

Test hypotheses	H_0 : The model is a PSTR with one threshold (r = 1)			
	H_1 : The model is a PSTR with at least two thresholds (r = 2)			
Order of function	m = 1		m = 2	
Wald Tests (LM) :	W = 8.441	pvalue = 0.134	W = 20.195	pvalue = 0.027
Fisher Tests (LMF) :	F = 1.556	pvalue = 0.175	F = 1.935	pvalue = 0.044

Source : Autors, WDI (2023).

Table 7 shows that, at a 1% significance level, the null hypothesis of a PSTR model with a single threshold cannot be rejected. There is only one transition function and one threshold for economic growth (r = 1, m = 1).

5.3 Final estimation of PSTR model

The results of the two-regime PSTR model estimation, with CO_2 emissions as the dependent variable, are presented in Table 8. One of the specific features of the PSTR model is that coefficients β_0 and β_1 cannot be directly interpreted, as there is an infinite range of coefficients between regimes. However, if the parameter β_1 has a negative sign, the impact of the explanatory variable on the dependent variable decreases as a function of the threshold variable (Eggoh and Villieu, 2013). Beyond a threshold of 8.4487, the PSTR model indicates a change in slope in the relationship between economic growth and pollution[2]. Therefore, the effect of economic growth on pollution is given:

$$\beta_0 \leq \frac{\partial CO_2}{\partial GDP} \leq \beta_0 + \beta_1 \text{ si } \beta_1 > 0$$

[2] Since GDP values are in logarithms, the threshold is obtained from the following formulas: lna = b and a = e^b.

$$\beta_0 + \beta_1 \leq \frac{\partial CO_2}{\partial GDP} \leq \beta_0 \text{ si } \beta_1 < 0$$

Table 8. Estimation of the PSTR with pollution as the dependent variable (CO_2)

Model	PSTR	
Variables	β_0	β_1
lnENG	0.846***	-0.095***
	(0.210)	(0.698)
	[4.024]	[-7.375]
lnDNS	0.584***	0.492***
	(0.129)	(0.151)
	[4.542]	[3.252]
lnIND	0.144	0.027
	(0.124)	(0.176)
	[1.166]	[0.155]
lnOUV	-0.073	0.234***
	(0.040)	(0.047)
	[-1.807]	[4.943]
FDI	0.010***	-0.013*
	(0.002)	(0.008)
	[4.133]	[-1.641]
(m^*, r^*)	(1,1)	(1,1)
Pente (γ)	118,405	118.405
Seuil (c)	3,108 (8.449)	3.108 (8.449)
RSS	0.864	0.864
AIC	-5.144	-5.144
BIC	-4.933	-4.933

Notes: Student's t statistics are in square brackets. Robust standard errors are in parentheses.
*** p<0,01 ; ** p<0,05 ; * p<0,1.
Source: Autors, WDI (2023).

In light of Table 8, we observe that the variables lnENG and lnDNS are significant at the 1% threshold. The variable lnIND has a positive but non-significant effect on CO_2 emissions in both the lower and upper regimes. The coefficient of the variable lnOUV is negative and non-significant in the lower regime but becomes positive and significant in the upper regime. Finally, the variable FDI is positive and significant at the 1% threshold in the first regime and negative and significant at the 10% threshold in the second regime.
The smoothing parameter gamma, which describes the speed of transition between the two extreme regimes, is relatively high and significant. This indicates that the transition from one regime to the other occurs quite abruptly. While a Panel Threshold Regression (PTR) model could have been sufficient to analyze the non-linear relationship between economic growth and pollution, the PSTR (Panel Smooth Threshold Regression) modeling is more comprehensive. It also has the advantage of providing elasticities derived from the weighting of variable coefficients in the extreme regimes.

5.4 Discussion of the results

The estimates reveal that the coefficient of the variable ENG (β_0) is positive, while the coefficient (β_1) is negative, both statistically significant. This suggests that an increase in energy consumption has a positive effect on CO_2 emissions in the first regime. This result confirms studies showing a positive relationship between energy consumption and pollutant emissions. These findings align with those of

Sotamenou and Nguepdjio (2019), who, using an ARDL model in Cameroon for the period 1975-2013, demonstrated that fossil and electrical energy consumption are sources of carbon emissions in the short term, though no long-term relationship exists between energy consumption and CO_2 emissions. Similarly, studies in Nigeria and Turkey have shown that increased energy consumption leads to higher CO_2 emissions (Akpan and Akpan, 2012). Beyond a certain GDP threshold, the influence of energy consumption on CO_2 emissions becomes negative. The results in the second regime corroborate the empirical literature, which supports a negative relationship between energy consumption and pollutant emissions.

Similarly, the coefficients (β_0) and (β_1) for the variable DNS are positive and significant. Population pressure is an explanatory factor for environmental quality. Indeed, population growth leads to increased food demands, overexploitation, reduction of natural resources, and a rise in pollutant emissions. This result is confirmed by Li and Ma (2014), and Begum and al. (2015). Moreover, Martinez-Zarzoso and al. (2006) revealed that in EU countries, population growth leads to increased CO_2 emissions.

Trade openness negatively impacts pollution in the first regime, though not significantly. The negative impact of trade openness on carbon emissions can be explained by the fact that accelerating international trade raises per capita income in these countries, prompting economic agents to focus more on environmental quality. This result confirms the findings of Magnani and Tubb (2007), who showed that trade openness negatively influenced emissions of certain pollutants (CO_2, SO_2, NO_2, etc.) in OECD countries. Similarly, Shafik and Bandyopadhyay (1992) argued that trade openness could reduce environmental degradation through technology transfer. However, beyond a certain GDP threshold, international trade significantly contributes to CO_2 emissions in ECOWAS countries. As these countries become more open to the world, their CO_2 emissions increase significantly. This is reflected in the scale effect: higher export levels require increased production, leading to more CO_2 emissions. This result supports Managi (2004), who found that international trade in both developed and developing countries increases environmental pressure.

Finally, FDI is significant and positive in the first regime. However, after a certain GDP threshold, the impact of FDI on environmental degradation becomes negative. CO_2 emissions were marginal over the study period, suggesting that FDI has a weak link with CO_2 emissions.

6. Conclusion and policy implications

This paper examined the relationship between economic growth and environmental pollution in ECOWAS countries using the PSTR model. From a methodological standpoint, the model relates CO_2 emissions to GDP per capita, biomass energy, fossil energy, population density, industry, trade openness, and FDI. The sample consists of 182 observations covering the period from 1996 to 2021. The data comes from the World Bank database (WDI, 2023).

Overall, the results show that, from a threshold of 8.4487, energy consumption, population density, trade openness, and FDI positively influence CO_2 emissions in ECOWAS countries. These findings support the Environmental Kuznets Curve (EKC) hypothesis. In light of these results, the study suggests that economic growth objectives should be accompanied by adaptation measures. Thus, these countries could benefit from: encouraging research in sustainable, low-emission renewable energies such as solar power to achieve decarbonized sustainable growth; ensuring the quality of FDI and industry migration; collecting and monitoring environmental indicators, then raising awareness about environmental risks; and finally, offering economic incentives to industries and populations. These incentives could take the form of a cap on total annual CO_2 emissions, a system of tradable emission quotas, or a carbon tax. However, it is important to note that these approaches should be adapted to the specific circumstances of each country.

References

[1] AIE (2014). « IEA Energy Technology Perspectives 2014, Harnessing Electricity Potential »,382 p.

[2] Akpan, E. G. & Akpan, F. U. (2012). Electricity Consumption, Carbon Emissions and Economic Growth in Nigeria, *International Journal of Energy Economics and Policy*, Vol 2, n° 4, 2012, pp. 292-306.

[3] Alkhathlan, K. & Javid, M. (2013). Energy consumption, carbone missions and economic growth in Saudi Arabia: An aggregate and disaggregate analysis, *Energy Policy* nº 62, 1525-1532. https://doi.org/10.1016/j.enpol.2013.07.068

[4] Begum, R. A., Sohag, K., Abdullah S. M. S. & Jaafar, M. (2015). CO_2 emissions, energy consumption, economic and population growth in Malaysia. *Renewable and Sustainable Energy Reviews*, n° 41, 5 p. https://doi.org/10.1016/j.rser.2014.07.205

[5] CCNUCC (2015). Document d'adoption de l'Accord de Paris, 12 décembre, Paris.

[6] Colletaz, G. & Hurlin, C. (2006). Threshold Effects in the Public Capital Productivity: An International Panel Smooth Transition Approach, *Working Paper*, 1/2006, LEO, Universite d'Orleans.

[7] Commission Mondiale sur l'Environnement et le Développement (CMED) (1987). *Notre avenir à tous. Rapport Brundtland.* Washington DC : ONU.

[8] Dinda, S. (2004). Environmental Kuznets Curve Hypothesis : A Survey, Ecological Economics, 49, 431-455. https://doi.org/10.1016/j.ecolecon.2004.02.011

[9] Eggoh, J. & Villieu, P. (2013). Un Réexamen de la Non-linéarité entre le Développement Financier et la Croissance Economique, *Revue d'Economie Politique*, 123, 211-236 https://doi.org/10.3917/redp.232.0211

[10] Fongnikin, J. P. & Lanha, M. (2020). Facteurs explicatifs de la dégradation de l'environnement dans quatre pays de l'UEMOA, *Journal d'Economie, de Management, d'Environnement et de Droit (JEMED)*, ISSN 2605-6461.Volume 3-Numéro 1-Février. 13 p.

[11] Gonzàlez A., Teräsvirta, T. & van Dijk, D. (2005). Panel Smooth Transition Regression Models, *Working Paper Series in Economics and Finance,* 604. Stockolm School of Economics.

[12] Grossman, G. M. & Krueger, A. B. (1995). Economic Growth and the Environment, *Quarterly Journal of Economics*, Vol 110 (2), pages 353-377. https://doi.org/10.2307/2118443

[13] Grossman, G. M. & Krueger, A. B. (1991). « *Environmental Impacts of the North American Free Trade Agreement*». In P. Garder (ed.), The U. S.-Mexico Free Trade Agreement, MIT Press, Cambridge, Massachusetts, Etats-Unis, https://doi.org/10.3386/w3914

[14] Gujarati, D. N. (2003). *Basic Econometrics.* 4th Edition, New Delhi: Tata McGraw-Hill, New York. P 748-807.

[15] Hansen, B. E. (1999). Threshold Effects in Non-Dynamic Panels: Estimation, Testing, and Inference, *Journal of Econometrics*, 93, 345-368. https://doi.org/10.1016/S0304-4076(99)00025-1

[16] Holtz- Eakin, D. & Selden, T.M. (1995). ''Stocking the fires? CO_2 emissions and economic growth', *Journal of Public Economics*, Vol.5, pp 85-101, https://doi.org/10.1016/0047-2727(94)01449-X

[17] Jevons, W. S. (1878). L'économie politique. Repéré à https:// classiques.uqac.ca/classiques/jevons_w_ stanley/economie_politique/jevons_ economie_ politique.pdf

[18] Khan, M. & Eggoh, J. (2021). Investigating the direct and indirect linkages between economic development and CO_2 emissions : à PSTR analysis. *Environmental Science and Pollution Research*, 28, 10039-10052, https://doi.org/10.1007/s11356-020-11468-7

[19] Kindleberger, C. P. (1986). International public goods without international government. *American Economic Revews*, 76, 1.

[20] Kuo, K. C., Kanyasathapom, P. & Lai, S. (2014). The Causal Relationship between GDP, Energy Consumption and CO_2 Emissions in Hong Kong, *Energy Education Science and Technology Part A: Energy Science and Research*, nº 32(1): 235-248.

[21] Li Sh & Ma, Y. (2014). Urbanization, Economic Development and environmental Change. Sustainability, nº 6, pp. 5143-5161. https://doi.org/10.3390/su6085143

[22] Liddle, B. & Lung, S. (2010). Age-structure, urbanization, and climate change in developing countries: Revisiting STIRPAT for disaggregated population and consumption-related environment impact. Population Environment 31, 317-343, https://doi.org/10.1007/s11111-010-0101-5

[23] Luukkonen, R., Saïkkonen, P. & Teräsvirta, T. (1988). " Testing Linearity against Smooth Transition Autoregressive Models", *Biometrika*, 75 (3): 491-499, https://doi.org/10.1093/biomet/75.3.491

[24] Magnani, E. & Tubb, A. (2007). The Link between Economic Growth and Environmental Quality: Does Population Ageing Matter? School of Economics Discussion Paper : 2007/12.

[25] Malthus, T. R. (1798). (1992). *Essai sur le principe de la population*. Paris: Flammarion.

[26] Managi, S. (2004). Trade Liberalization and the Environmental: Carbon Dioxide for 1960-1999. Economics Bulletin 17 (1), 1-5.

[27] Martinez- Zarzoso, I., Bengochea-Morancho, A. & Morales-Lage, R. (2006). The Impact of Population on CO_2 Emissions: Evidence from European Countries. Fondazione ENI Enrico Mattei, Nota dilavaro N.98. https://doi.org/10.2139/ssrn.902703

[28] Maslow, A. H. (1943). A theory of human motivation, *Psychological Review*, 50(4), 370-396, https://doi.org/10.1037/h0054346

[29] Menyah, K. & Wolde-Rufael, Y. (2010). Energy consumption, pollutant emissions and economic growth in South Africa, *Energy Economics* 32 (2010), 1374-1382, https://doi.org/10.1016/j.eneco.2010.08.002

[30] Mill, J. S. (1848). Principles of Economics, Livres I, II, III, IV et V.

[31] OCDE (2002). Pour une croissance écologiquement viable : l'expérience des pays de l'OCDE.

[32] Ozturk, I. & Acaraci, A. (2010). ''CO_2 emissions, energy consumption and economic growth in Turkey'', *Renewable and Sustainable Energy Reviews,* 14, pp. 3220-3225, https://doi.org/10.1016/j.rser.2010.07.005

[33] Panayotou, T. (2003) : '' Economic growth and the environment", Economic Survey of Europe, N° 2.

[34] Parikh, J. & Shukla, V. (1995). ''Urbanization, energy use and greenhouse effects in economic development''. Global Environmental Change, 5(2), 87-103, https://doi.org/10.1016/0959-3780(95)00015-G

[35] Pesaran M. H. (2004). « General Diagnostic Tests for Cross Section Dependence in Panels. » CES ifo Working Paper no. 1229, CES ifo Group Munich, 2004, https://doi.org/10.2139/ssrn.572504

[36] PNUD (2003). « Rapport sur le Développement Humain au Bénin (2003) : Le financement du Développement Humain » ; Cotonou.

[37] Ricardo, D. (1817). *Principes de l'économie et de l'impôt, Quarterly Journal of Economics (Q J E)*, MIT Press, Harvard University.

[38] Shafik, N. & Bandyopadhyay, S. (1992). Economics growth and environmental quality: times series and cross- country evidence. Background paper for the World Development Report 1992 (Washington, DC: The World Bank, 1992).

[39] Shahbaz, M., Haouas, I., Sbia, R., & Ozturk, I. (2018). Financial Developpement-Environmental Degradation Nexus in the United Arab Emirates: The Importance of Growth, Globalization and Structural Breaks.

[40] Shahbaz, M., Sbia, R., Hamdi, H. & Ozturk, I. (2014). ''Economic growth, electricity consumption, urbanisation and environmental degradation relationship in United Arab Emirates'', Ecological Indicators, 45 622-631. https://doi.org/10.1016/j.ecolind.2014.05.022

[41] Smith, A. (1776). *Vertus de la division du travail. Quarterly 2Journal of Economics (Q J E)*, MIT Press, Harvard University.

[42] Solarin, S. A., Al-Mulali, U. & Ozturk, I. (2017). Validating the environmental Kuznets curve hypothesis in India and China: The role of hydroelectricity consumption. *Renewable and Sustainable Energy Reviews*, 80, 1578-1587. https://doi.org/10.1016/j.rser.2017.07.028

[43] Sotamenou, J. & Nguepdjio, C. N. (2019). Consommation d'énergie, croissance économique et émissions de de CO_2 au Cameroun : une analyse de causalité. *African Integration and Development Revew*, Volume 11-Numéro 1-March, pp. 82-100.

[44] Talukdar, D. & Meisner, C.M. (2001). Does the private sector help or hurt the environment? Evidence from carbon dioxide pollution in developing countries. World Development, 29(5), p.827-840. https://doi.org/10.1016/S0305-750X(01)00008-0

[45] Teräsvirta, T. (1994). ''Specification, Estimation, and Evaluation of Smooth Transition Autoregressive Models'', *Journal of the American Statistical Association*, 89: 208-18. https://doi.org/10.1080/01621459.1994.10476462

[46] Tietenberg, T. & Lewis, L. (2013). *Economie de l'environnement et développement durable,* 6eme édition, Collection « Nouveaux Horizons », 390 p.

[47] Van Dijk, D., Terasvirta, T. & Franses, P.H. (2002). Smooth Transition AutoRegressive Models: A Survey of Recent Developments., Econometric Reviews, 21, pp. 1-47. https://doi.org/10.1081/ETC-120008723

[48] Van Duysen, J-C. & Jumel, S. (2008). *Le développement durable* : le HARMATTAN Paris 2008.

[49] Walras, L. (1875). ''L'Etat et les chemins de fer'', in Etudes d'économie politique appliquée, vol. X, Paris, Economica, 1992, pp. 183-214.

[50] Wang, C. M. (2010). "*Decoupling analysis of China economic growth and energy consumption. China Population*", Resources and Environment, Vol. 20(3), pp 35-37.

[51] Wang, Q., Wang, X. & Li, R. (2022). Does urbanization redefine environmental Kuznets curve? An empirical analysis of 134 Countries. *Sustainable Cities and Society*, 76, 103382. https://doi.org/10.1016/j.scs.2021.103382

[52] WDI (2023). *World Development Indicator Data base*, world Bank, 2023.

[53] World Health Organization (2008). World Health Organization, Public Health and Environment, HPE-WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide -Global up date 2008 http:// whqlibdoc.who.into/ hq/2008/who_sde_phe_ oeh_08.02_fre.pdf

[54] Zhang, C., Zhou, K., Yang, S. & Shao, Z. (2017). On electricity consumption and economic growth in China. Renewable and Sustainable Energy Reviews, 76:353-368. https://doi.org/10.1016/j.rser.2017.03.071

[55] Zhu, H-M., You, W-H. & Zhao-Fa, Z. (2012). Urbanization and CO_2 emissions: A semi-parametric panel data analysis. Economics Letters 117, 848-850. https://doi.org/10.1016/j.econlet.2012.09.001