International Journal of Economics and Finance; Vol. 16, No. 1; 2024
ISSN 1916-971X E-ISSN 1916-9728
Published by Canadian Center of Science and Education

Economic Growth and Carbon Dioxide Emissions in Côte d'Ivoire: An Empirical Analysis of the Environmental Kuznets Curve Hypothesis

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Received: November 8, 2023 Accepted: December 25, 2023 Online Published: December 30, 2023

doi:10.5539/ijef.v16n1p85 URL: https://doi.org/10.5539/ijef.v16n1p85

Abstract

The objective of this paper is to investigate the existence of the environmental Kuznets curve (EKC) hypothesis in the economy of Côte d'Ivoire using annual time series data of GDP per capita and CO2 emissions over the period 1970-2016. The ARDL bound test approach proposed and applied by Pesaran et al. (2001) indicates a long-run relationship between economic growth and CO2 emissions. The existence of a causal relationship between economic growth and CO2 emissions is confirmed by VECM Granger causality approach. Using an ARDL model, our results confirm the existence of an environmental Kuznets curve for CO2 emissions. In the long-run, the turning point is 1.826459 thousand US dollars, and this point has been reached for the case of Côte d'Ivoire according to the data in our study. Consequently, we suggest that Côte d'Ivoire implement on the one hand specific and sustained policies to increase GDP per capita to improve environmental quality, and on the other hand implement environmentally friendly regulations to support the country's economic development.

Keywords: EKC, CO2 emissions, ARDL model, Côte d'Ivoire

1. Introduction

For a long time, politicians considered that economic growth was only partially linked to CO2 emissions. It was optimistically assumed that, with growth, energy consumption would increase much less than GDP. This optimistic idea was based on the hypothesis of the environmental Kuznets curve (EKC). The interest of the EKC is that it postulates the possibility for poor countries to improve environmental quality as they develop and as the standard of living of individuals improves, thus fostering the emergence of an environmental conscience (Banque, 1992). In the early 90s, a number of scientific studies set out to test the environmental Kuznets curve hypothesis between economic growth and indicators of environmental degradation (SO2, NOX, CO2, CO, municipal waste and suspended particulates) (Grossman & Krueger, 1995; Panayotou, 1993; Shafik & Bandyopadhyay, 1992; Selden & Song, 1994). Several authors have offered a detailed review of empirical work on the relationship between economic growth and environmental quality, using per capita CO2 emissions as an indicator of environmental quality (Jalil & Mahmud, 2009; Shahbaz et al., 2014; Raheen & Ogebe, 2017; Domguia & Ndieupa, 2017). The diversity of work confirms that environmental problems differ from region to region and country to country.

Today, we are witnessing an accumulation of environmental problems caused by human activities and the damage caused by CO2 emissions. Climate change around the world is exacerbating extreme weather events and increasing the risk of climatic catastrophes. Rising air and water temperatures are causing sea levels to rise and increasing the intensity of storms, winds, droughts and fires, which last longer, as well as rainfall and flooding. According to the GIEC (2021), climate change will become more pronounced in all regions over the coming decades, with more heat waves, longer hot seasons and shorter cold seasons. Greenhouse gases (GHGs) increased by around 70% between 1970 and 2004. CO2 alone, which accounts for 77% of these gases, increased by 80% over the same period (GIEC, 2007).

In a global context increasingly concerned about climate change, understanding the impact of economic growth on CO2 emissions is becoming crucial, especially for a developing country like Côte d'Ivoire. This paper looks at this issue through the prism of carbon dioxide CO2 emissions through increasing industrialization and urbanization, and examines how economic growth affects the Ivorian environment. The paper looks at the link between economic prosperity and carbon footprint. This means that economic growth would have a causal link with CO2 emissions. The aim of this study is also to test the validity of the environmental Kuznets curve (EKC) for the case of Côte d'Ivoire. To this end, the ARDL (Auto Regressive Distributed Lag) method is used to study both the short-run and long-run elasticities of the variables.

As a temporal lag model, the ARDL model provides a better approximation of economic reality and an accurate measure of the consequences of certain economic policy measures. In its specification, time lags can relate to the endogenous and/or exogenous variables. When the lagged endogen appears as an explanatory variable, the model is said to be autoregressive. When the lags concern only the exogenous variables, the model is said to be staggered lag. The combination of these two types of models leads to Auto Regressive Distributed Lag models (ARDL) (Keho, 2012). Taken from the World Bank's World Development Indicators (WDI, 2023) last updated 015/09/2023, the data in our study cover the period 1970-2016 and are estimated using Eviews 9 software. We restrict ourselves to this period due to data availability.

Our estimates indicate the existence of a long-run relationship and a causal relationship in the Granger sense between economic growth and CO2 emissions. The estimated ARDL model confirms the existence of an environmental Kuznets curve for CO2 emissions in Côte d'Ivoire in the long-run. The specificity of our study is that, in addition to confirming the ECK hypothesis, we determine a turning point for CO2 emissions in Côte d'Ivoire which is 1.826459 thousand US dollars, unlike the work of Keho (2015), who carried out a study on the long-run determinants of CO2 emissions in Côte d'Ivoire, also confirming the ECK hypothesis. The turning point is an indicator that detects when CO2 emissions in Côte d'Ivoire turn around after reaching the peak. This turning point of 1.826459 lies between the minimum GDP value of 1.138665 and its maximum value of 2.471015 (see table 2). In other words, the turning point has been reached for Côte d'Ivoire, according to our estimate. Reaching this turning point means that people in Côte d'Ivoire have become more aware of the quality of the environment, and this is due to the growth of a middle class concerned about and demanding a quality living environment.

Based on these results, we suggest that Côte d'Ivoire implements specific and sustained policies to increase GDP per capita in order to improve environmental quality. The Ivorian authorities must also implement specific policies to significantly reduce carbon dioxide emissions. To this end, we suggest a carbon pricing policy and strategies to promote and develop clean, renewable energies. As for the promotion and development of clean and renewable energies, this requires necessary institutional regulations. Thus, regulatory instruments will provide incentives for the spread of clean technologies and help reverse the trend towards rising CO2 emissions.

As with any research work, and despite the precautions taken a priori to ensure the validity of the results, there may be limitations. The lack of data for some of the more relevant control variables meant that we limited ourselves to just four control variables: GDP per capita, GDP per capita squared, industrialization and urbanization. Also, the use of quarterly or half-yearly data instead of annual data could influence the final results and allow for a different point of view in terms of discussion.

The work is organized as follows. In section 2, we briefly review the literature on EKC based on the relationship between economic growth and CO2 emissions. Section 3 provides an assessment of CO2 emissions in Côte d'Ivoire. Section 4 describes the data used. Section 5 describes the econometric models used for the estimation. Section 6 presents the empirical results. Section 7 discusses and concludes the findings.

2. Literature Review

According to some experts, economic growth leads to the creation of activities that consume a lot of energy and are therefore much more polluting (Foster & Elzinga, 2016; Tzete et al., 2022). But in the 1990s, this idea was challenged by the EKC hypothesis that economic growth, by raising the level of per capita income, would lead to an improvement in the quality of the environment and the living conditions (Beckerman, 1992). The literature on the relationship between economic growth and the environment initiated by Grossman and Krueger (1991, 1995), Shafik and Bandyopadhyay (1992) and Selden and Song (1994) hypothesizes the existence of an environmental Kuznets curve (EKC) inspired by the results of the Kuznets (1955) study on economic growth and inequality. The EKC hypothesis states that, for a given country, environmental degradation initially increases with rising per capita income, reaching a threshold or turning point before gradually decreasing in a second phase, thus describing an inverted U-shaped curve between per capita income and environmental pollution. The reversal of the curve's trend can be explained, among other things, by the changing preferences of the population, which attaches greater importance to environmental goods and facilities when it reaches a sufficiently high standard of living. In other words, people's willingness to pay for a high-quality environment increases by a greater proportion than income (Baldwin, 1995; Roca, 2003; Dinda, 2004). Grossman (1995) summarizes and breaks down the two phases of ECK into three successive effects of economic development on the environment. These are a scale effect (i.e., high production of goods and services generates high pressure on the environment and causes more pollution), a composition effect (i.e., the evolution of the economy towards a cleaner, human-capital-intensive and environmentally conscious production system) and finally a technical effect due to massive investment in R&D for more efficient and environmentally-friendly production techniques.

The scientific works that have verified the existence of this hypothesis using carbon dioxide CO2 as an indicator of environmental degradation are numerous. We can cite Jalil and Mahmud (2009), Shahbaz et al. (2014), Keho (2015), Raheen and Ogebe (2017) and Koilo (2019). However, the empirical robustness of this hypothesis still remains a matter of debate according to Dasgupta et al. (2002).

For example, using an ARDL model, Jalil and Mahmud (2009) examined the long-run relationship between carbon emissions and energy consumption, income and foreign trade in the case of China, using time-series data from 1975 to 2005. Their study aimed to test whether EKC's relationship between CO2 emissions and real GDP per capita holds in the long-run or not. Their results also indicate that carbon emissions are mainly determined by income and energy consumption in the long-run. They also show the existence of a quadratic relationship between income and CO2 emissions was found for the sample period, supporting the EKC relationship. Shahbaz et al. (2014) test the EKC hypothesis between economic growth and CO2 emissions, and also argue that high energy consumption and trade openness contribute to CO2 emissions. Their results also indicate that energy consumption is a major contributor to energy pollutants. In a study of the long-run determinants of CO2 emissions in Côte d'Ivoire, Keho (2015) also observes EKC. More interestingly, his results show that as the country industrializes, its CO2 emissions increase. Furthermore, he finds that trade openness and industrialization are complementary in the degradation of environmental quality in Côte d'Ivoire.

Raheen and Ogebe (2017), in a study of 20 African countries over the period 1980-2013, adopted estimates using the Mean Group (MG) and the Pooled Mean Group (PMG). Their results confirm the existence of the EKC hypothesis for Africa. In their view, the continent's desire to increase its level of industrialization has coincided with an increase in the growth rate of urbanization, as well as in the income level of former rural dwellers. According to the authors, industrialization and urbanization, with their direct and indirect effects on carbon emissions, directly increase environmental degradation through their indirect effects on per capita income. Koilo (2019) investigates the relationship between economic development measured by economic growth, energy consumption, trade, foreign direct investment and environmental degradation (carbon dioxide emissions), in eleven emerging countries in Eastern Europe and Central Asia over the period 1990-2014. The concludes that the EKC hypothesis exists between economic growth and CO2 emissions for all eleven countries.

Some authors do not find results validating the EKC hypothesis between economic growth and CO2 emissions. For the latter, there is a negative effect of total energy consumption on the environment, mainly through increasing industrialization, since such consumption increases CO2 emissions. We can cite Halicioglu (2009), González and Martínez (2012), Chandran and Tang (2013), Lin et al. (2016), Domguia and Ndieupa (2017), Rauf et al. (2018), Lin and Chen (2020) and Shikwambana et al. (2021).

For example, Halicioglu (2009) empirically examines the dynamic causal relationships between carbon emissions, energy consumption, income and foreign trade in the case of Turkey, using time series data for the period 1960-2005. The results suggest that income is the most significant variable in explaining carbon emissions in Turkey, followed by energy consumption and foreign trade. He finds no evidence of EKC between income and carbon emissions. González and Martínez (2012) analyze the intensity of CO2 emissions in Mexican industry from 1965 to 2010. They consider four periods: 1965-1982, 1982-1994, 1994-2003 and 2004-2010. They use the LMDI (Logarithmic Mean Divisea Index) decomposition methodology, and find no evidence of EKC between the national economy and CO2 emissions. Nonetheless, industries such as automotive and others have grown significantly, not only in terms of their energy consumption and related CO2 emissions, but also in terms of their contribution to the national economy.

Chandran and Tang (2013) in their study assess the impact of transport sector energy consumption and foreign direct investment on CO2 emissions for ASEAN-5 economies. They use Granger's cointegration and causality methods. Their results indicate that economic growth plays a more important role in the contribution to CO2 emissions in ASEAN-5. However, there is no evidence for the existence of the EKC hypothesis between economic growth and CO_2 emissions. The inverted-U-shaped EKC hypothesis is not applicable to ASEAN-5 economies, particularly Indonesia, Malaysia and Thailand. Conducted in China, from 1968 to 2016 using an ARDL model to examine the link between the variables; energy consumption, economic growth, agricultural value added, industrial value added, service value added, trade openness, financial development, urbanization and environmental degradation (CO_2 emission), Rauf et al. (2018) find no evidence of EKC between economic growth and carbon emissions in China. Similarly, Lin and Chen (2020) find that land transport infrastructure, economic growth, technological progress, energy prices, industrial structure have a significant impact on the energy and environmental efficiency of China's manufacturing industry. But there is no evidence of an EKC between economic growth and carbon emissions in China. Also, Lin et al. (2016) finds no evidence for the existence of the EKC between economic growth and carbon emissions in China.

Domguia and Ndieupa (2017) find the existence of a long-run relationship in the form of an "inverted N" between economic growth and CO_2 emissions, but find no evidence for the existence of EKC between economic growth and carbon emissions in Cameroon. Shikwambana et al. (2021) establish a relationship between economic growth and pollutant emission levels (namely carbon dioxide (CO_2), black carbon (BC) sulfur dioxide (SO_2) and carbon monoxide (CO)) in South Africa, for the period 1994 to 2019. They use the linear correlation coefficient, the EKC assumption to determine relationships and the Sequential Mann-Kendall test (SQMK) to investigate trends. The results show a correlation coefficient of 0.84, indicating a strong positive linear correlation between GDP and CO_2 emissions. EKC's hypothesis analysis instead showed an N-shape for SO_2 and CO. Overall, their results indicate that emission levels are generally correlated with economic growth. Consequently, a rigorous regulatory system is needed to reduce the high emission levels observed, given the importance of economic growth. Overall, even if not all the results validate the CEK hypothesis between economic growth and CO_2 emissions, we note that numerous studies at least confirm the sensitivity and positive relationship between economic growth and CO_2 emissions (Magazzino, 2014; Akin, 2014).

3. Assessment of CO2 Emissions in Côte d'Ivoire

Mindful of the risks associated with high energy consumption due to increasing industrialization and urbanization, and in particular CO_2 emissions into the atmosphere, Côte d'Ivoire signed the United Nations Framework Convention on Climate Change (UNFCCC) in June 1992 at the Earth Summit in Rio de Janeiro, Brazil. In article 12, the Convention sets out the long-run objective for signatory countries to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system within a time-frame that would allow ecosystems to adapt adequately to climate change, so that global food production is not threatened and economic development can proceed in a sustainable manner". However, despite the ratification of the said Convention on November 20, 1994 by the State of Côte d'Ivoire, greenhouse gas emissions are increasing. In an initial submission to the UNFCCC by the Ministry of the Environment, Water and Forestry in October 2000, Côte d'Ivoire's greenhouse gas emissions included carbon dioxide (CO_2), methane (CH) and nitrous oxide (N_2O), nitrogen oxides (NO_x) and carbon monoxide (CO). For CO_2, the inventory concludes with a total emission value of -17901.47 Gg (Gigagram), indicating that the country is a net greenhouse gas (GHG) sink. The results of the forestry module for the 2034 horizon, according to one of the hypotheses, indicate that the carbon sequestration rate should increase from 130tC/ha to 307 tC/ha, i.e. from 301 to 486 million tons of Carbon from 2015 to 2034. As for waste, CH_4 emissions rose from 21.41 to 45.15Gg between 1995 and 2015 (Ministère de l'environnement de l'eau et de la forêt, 2000).

According to a report by the Japan International Cooperation Agency (JICA) (2019), GHG emissions in the energy sector emanate mainly from the carbon combustion of the various fuels used. Hydroelectricity is one of the few sources of emission-free energy. Where gas emissions do occur, CO_2 and CH_4 are the most significant components of GHG emissions in Côte d'Ivoire. But it should be noted that NOX and CO are also significant emissions from fuel combustion. According to the Ministry of the Environment, apart from the industrial and energy production sectors, transport today represents a major hydrocarbon consumption sector in Côte d'Ivoire, and therefore contributes on a large scale to GHG emissions. This includes air, road, rail and sea transport, whose total consumption of petroleum products is estimated at 44036.27 TJ (terajoule). CO_2 emissions from fossil fuels account for 97% of total emissions.

4. Econometric Method

4.1 Data and Variables

The variable $CO2_t$ represents carbon dioxide emissions in kilotons. Carbon dioxide (CO_2) is a colorless, odorless and non-toxic gas, formed during the combustion of carbon and the respiration of living organisms, and considered a GHG. GDPt represents GDP per capita in thousands of constant 2010 US dollars. This variable is used in economic literature as an indicator that reflects the increasing level of economic activity in a country. On a per capita basis, it shows the share of wealth held by each individual, taking demographic fluctuations into account. The INDt variable represents the added value of industry as a % of GDP. The presence of this variable in the study is explained by the fact that industry is estimated to represent one of the major sectors of the global economy contributing to CO2 emissions, with an estimated share of 21%; behind heat and power generation 25% and agriculture, forestry and land use 24% (GIEC, 2015). In particular, industrialization has accelerated the exploitation of natural resources and generated numerous pollutions that continue to have significant impacts on the environment.The variable URBt represents the urban population as a % of the total population. Today, demand for manufactured goods is increasing with the rise in middle-class consumption among Ivorian urban populations, and this shift in consumption patterns thus offers a significant opportunity for industrialization (Nations Unies, 2017). However, while most studies refer to urbanization and industrialization as important drivers of income, they argue that both are also direct and indirect sources of carbon emissions (Xu & Lin, 2015; Raheen & Ogebe, 2017).

Table 1 below presents the different variables used in our study. Table 2 provides statistical information on the model variables. Our results (see Table 2) show that the variable GDP per capita in thousands of US dollars has the lowest minimum value of 1.138 and its maximum is 2.471, with a mean of 1.578. Next comes CO2 emissions in kilo tons, with a minimum value of 7.800 and a maximum of 9.309, with an average of 8.689. The table also shows that the urban population variable is more volatile than the other variables, with a standard deviation of 5.782. The CO2 emissions variable is the least volatile, with a standard deviation of 0.361.

Table 1. Variable description

Variables	Symbols	Descriptions and units of measurement	Data sources
CO2 emissions	*CO2*	CO2 emissions in kilo tons	WDI
GDP per capita	*GDP*	GDP per capita in thousands of constant 2010 US dollars	WDI
Industrialization	*IND*	Industrial added value as % of GDP	WDI
Urbanization	*URB*	Urban population as % of total population	WDI

Source: The authors.

Table 2. Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
LNCO2	47	8.689933	0.361649	7.800664	9.309733	-0.479923	2.774742
GDP	47	1.578136	0.375585	1.138665	2.471015	0.375585	0.874250
GDP2	47	2.628575	1.313208	1.296558	6.105917	1.129177	3.172695
IND	47	21.53160	2.925880	15.15722	27.41005	-0.262637	2.497392
URB	47	40.45730	5.782906	28.16300	49.88100	-0.304861	2.351090

Source: The authors.

4.2 Model Specification

The aim of our study is to assess the links between economic prosperity and carbon footprint in Côte d’Ivoire. The general model to be estimated is inspired by the work of Haouraji et al. (2021) and Jóźwik et al. (2022) and is as follows:

$$LNCO2_t = \beta_0 + \beta_1 GDP_t + \beta_2 GDP2_t + \beta_3 IND_t + \beta_4 URB_t + e_t \tag{1}$$

with t = 1970, 1981, 1982, ..., 2016, a period of 47 years; e_t and is the error term, $e_t \backsim iid(0,\sigma)$. GDP2t is the square of GDP per capita. The existence of the EKC hypothesis will have to indicate that the parameter β_1 is of positive sign and that of the parameter β_2 is negative. In other words, EKC translates into an inverted U-shaped curve. This implies that economic growth initially increases CO2 emissions and reduces them when the economy is prosperous.

5. Estimation Strategy

5.1 Unit Root Test

In this study, we use the unit root test of Zivot and Andrews (1992) to capture breaks in series. The Zivot and Andrews (1992) (ZA) test is a unit root test with an endogenous break. These two authors develop Perron’s (1989) test to render the break endogenous. Zivot and Andrews (1992) have eliminated the disadvantage of the absence of structural break points by developing three new econometric models. These econometric models are very useful for studying the stationarity properties of macroeconomic variables in the presence of structural breakpoints in the series. These models allow for a one-off change in the level of the variables (model A), a one-off change in the slope of the trend component, i.e. the trend function (model B), and one model has a stationarity function with a single change in both the intercept and trend function of the variables (model C). The three models adopted by Zivot and Andrews (1992) to test the hypothesis of a unique structural break in the series as follows:

$$\Delta x_t = \alpha + \alpha_{t-1} + bt + cDU_t + \sum_{j=1}^{k} d_j \Delta x_{t-j} + \mu_t \tag{2}$$

$$\Delta x_t = b + bx_{t-1} + ct + bDT_t + \sum_{j=1}^{k} d_j \Delta x_{t-j} + \mu_t \tag{3}$$

$$\Delta x_t = c + cx_{t-1} + ct + dDU_t + dDT_t + \sum_{j=1}^{k} d_j \Delta x_{t-j} + \mu_t \tag{4}$$

In the above equations, the dummy variable is represented by DUt showing the change in mean occurring at each breakpoint in time, while the trend change variables are represented by DTt. Thus,

$$DU_t = \begin{cases} 1 ... if\ t \text{ f } TB \\ 0 ... if\ t \text{ p } TB \end{cases} \quad and \quad DT_t = \begin{cases} t - TB ... if\ t \text{ f } TB \\ 0 ... if\ t \text{ p } TB \end{cases}$$

The null hypothesis of the unit root break date is $c = 0$, which indicates that the series is non-stationary with a derivative having no information on the structural break point while the hypothesis $c \text{ p } 0$ implies that the variable turns out to be trend-stationary with an unknown time break. The unit root test of Zivot and Andrews (1992) fixes all points as potential for a possible temporal break and estimates by regression for all possible break points successively. Then, this unit root test selects this temporal break, which reduces the one-sided t-statistic to test $\hat{c}(= c - 1) = 1$.

5.2 Cointegration Method

There are many statistical methods for testing a cointegrating relationship between variables. In this study, we use Johansen's (1988) test, which applies only to variables integrated at the same order, and the ARDL cointegration approach proposed by Pesaran et al. (2001), which applies regardless of whether the variables are I(0), I(1) or mutually cointegrated. Johansen's (1988) cointegration test procedure is based on the maximum likelihood method and offers the possibility of taking into account several specifications for the long-term relationship (presence of a constant/trend or not in the cointegration space). The test is based precisely on determining the rank of the matrix Π, denoted as r; r represents the number of cointegration relationships, from the trace statistic and the maximum eigenvalue statistic. The trace statistic is as follows:

$$Trace(H_0(r) / H_1(k) = -T \sum_{i=r+1}^{p} \ln(1 - \phi_i) \tag{5}$$

with ϕ_i the ith estimated maximum eigenvalue. We test the null hypothesis $H_0(r)$: rank $(\Pi) = r$, of cointegration rank r (number of long-term vectors or cointegrating relationships) against the alternative hypothesis $H_1(k)$: rank $(\Pi) = k$. The null hypothesis is rejected when the calculated statistic is below the critical value. The maximum eigenvalue statistic is:

$$\phi_{\max}(H_0(r) / H_1(r+1)) = -T(1 - \phi_{r+1}) \tag{6}$$

with ϕ_{r+1} the ith estimated maximum eigenvalue. We also test the null hypothesis $H_0(r)$: $(\Pi) = r$ (cointegration number) against the alternative hypothesis $H_1(k)$: rank $(\Pi) = r + 1$. The null hypothesis is rejected when the calculated statistic is below the critical value. The cointegration test procedure proposed by Pesaran et al. (2001), known as the ARDL cointegration bound test, is an unbiased, efficient cointegration technique that performs well in small samples (Narayan, 2004). It is applied on the basis of an ARDL cointegration specification. The test procedure assumes the existence of long-run equilibrium relationships. These relationships can be combined with the short-run dynamics of the series in a dynamic unrestricted error correction model (UECM), which when applied to Model 1 takes the following form:

$$\begin{aligned}\Delta \ln CO2_t = {} & \vartheta_1 + \vartheta_2 DUM + \vartheta_3 \ln CO2_{t-1} + \vartheta_4 GDP_{t-1} + \vartheta_5 GDP_{t-1}^2 \\ & + \vartheta_6 IND_{t-1} + \vartheta_7 URB_{t-1} + \sum_{j=1}^{p} \vartheta_j \Delta \ln CO2_{t-j} \\ & + \sum_{k=0}^{q} \vartheta_k \Delta GDP_{t-k} + \sum_{l=0}^{r} \vartheta_l \Delta GDP_{t-l}^2 + \sum_{m=0}^{s} \vartheta_k \Delta IND_{t-m} \\ & + \sum_{n=0}^{t} \vartheta_k \Delta URB_{t-n} + e_i \end{aligned} \tag{7}$$

Where Δ is the difference operator, DUM is a dummy variable to capture the structural break from the series and e_i is the residual term assumed to have a normal distribution with finite variance and zero mean. The next step is to calculate the F-statistic of the ARDL to examine whether or not cointegration between variables exists. It is necessary to choose an appropriate lag order for the variables, as the value of the F-statistic varies with the lag order. We use the Akaike Information Criterion (AIC) to select the appropriate lag length. We apply the F-test developed by Pesaran et al. (2001) to examine the joint significance of estimates of the lagged level of the series. The null hypothesis of no cointegration is as follows: $H_0 : \vartheta_3 = \vartheta_4 = \vartheta_5 = \vartheta_6 = \vartheta_7 = 0$ and the cointegration hypothesis is: $H_0 : \vartheta_3 \neq \vartheta_4 \neq \vartheta_5 \neq \vartheta_6 \neq \vartheta_7 \neq 0$. The calculated value of the Fisher F-statistic is compared with the critical values forming the upper bound (UB) and lower bound (LB) provided by Pesaran et al. (2001). If the F-statistic is greater than the UB, cointegration exists. There is no cointegration if the F-statistic is below the LB. If the F-statistic lies between the two bounds, the test is inconclusive.

5.3 Granger Causality Test

We apply the vector error correction model (VECM) to investigate the causal relationship between variables once the cointegrating relationship exists between the series. This VECM model by Granger (1969) is an appropriate approach for examining causality between variables when the series are integrated of order 1, i.e. I (1) as is the case in this study (See unit root test results in Table 5). The empirical equation of the Granger VECM causality approach is modeled as follows:

$$(1-L)\begin{bmatrix} \ln co2_t \\ gdp_t \\ gdp_t^2 \\ ind_t \\ urb_t \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} + \sum_{i=1}^{p} (1-L) \begin{bmatrix} b_{11i} b_{12i} b_{13i} b_{14i} b_{15i} \\ b_{21i} b_{22i} b_{23i} b_{24i} b_{25i} \\ b_{31i} b_{32i} b_{33i} b_{34i} b_{35i} \\ b_{41i} b_{42i} b_{43i} b_{44i} b_{45i} \\ b_{51i} b_{52i} b_{53i} b_{54i} b_{55i} \end{bmatrix} \times \begin{bmatrix} \ln co2_{t-1} \\ gdp_{t-1} \\ gdp_{t-1}^2 \\ ind_{t-1} \\ urb_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha \\ \beta \\ \delta \\ \phi \\ \vartheta \end{bmatrix} ECT_{T-1} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \end{bmatrix} \tag{8}$$

Where $(1-L)$ indicates the difference operator and the lagged residual term is indicated by ECT_{T-1} which is obtained from the long-run relationship while ε_{1t}, ε_{2t}, ε_{3t}, ε_{4t} and ε_{5t} are error terms. These terms are assumed to be homoscedastic, i.e. with constant variance. The statistical significance of the coefficient of the lagged error term, i.e. ECT_{T-1} using t-statistics, shows a long-run causal relationship between the variables. Short-run causality is demonstrated by the statistical significance of the F-statistic using the Wald test, incorporating the difference and lag of the independent variables into the model. In addition, the joint significance of the lagged error term with the differentials of the independent variables provides joint long-run and short-run causality.

Note, however, that the Granger VECM causality test does not determine the relative strength of the causal effect beyond the selected period (Shan, 2005; Shahbaz et al., 2012). It is unable to indicate the degree of feedback from one variable to another. To overcome the shortcoming of this test, we use a new approach: the variance decomposition method. This new approach also avoids the problem of endogeneity and series integration, and only shows the causal relationship between variables during the sampling period.

Pesaran and Shin (1999) point out that the variance decomposition method shows the proportional contribution of one variable due to innovative shocks from other variables. The main advantage of this approach is that it is insensitive to the order of the variables, because the order of the variables is uniquely determined by the VAR system. In addition, the variance decomposition approach estimates the simultaneous effects of shocks. Engle and Granger (1987) and Ibrahim (2005) have argued that with the VAR framework, the variance decomposition approach produces better results than other traditional approaches. Finally, to validate our ARDL model, we perform diagnostic tests. These are the Jarque-Bera normality test, the Breusch-Godfrey autocorrelation test, the White and ARCH heteroskedasticity tests and the Ramsey misspecification test. Finally, we test the stability of the coefficients using the Cumulative Sum (CUSUM) and the Cumulative Sum of Squares (CUSUMSQ).

6. Empirical Results

6.1 Correlation and Causality Between Variables

According to our results, the optimal number of lags is two $(p = 2)$ according to the following information criteria: sequential modified LR test statistic (each test at 5% level) (LR), Final prediction error (FPE), Akaike information criterion (AIC) and Hannan-Quinn information criterion (HQ). We therefore specify a VECM Granger causality test. Tables 3 and 4 below show the correlation matrix between variables and the results of the VECM Granger causality test.

Table 3. Correlation matrix between variables

Variables	*LNCO2*	*GDP*	*GDP2*	*IND*	*URB*	*VIF*
LNCO2	1					
GDP	-0.60041	1				3.356616
GDP2	-0.59408	0.995618	1			
IND	0.633119	-0.78917	-0.79791	1		3.124043
URB	0.835966	-0.78655	-0.75743	0.768301	1	3.090299

Source: The authors.

The correlation matrix between the variables tells us that the explanatory variable urbanization (URB) is linked to the dependent variable (LNCO2), as their degree of correlation is 0.83 greater than 0.8 in the first column. This 0.83 value tells us that the two variables are highly correlated, and leads us to suspect multicollinearity. However, calculation of the variance inflation factor (VIF) gives VIF values all below 5. This means that there is no multicollinearity.

Table 4. VECM Granger causality test results

Variables	Short run					Long run
dépendantes	*LNCO2*	*GDP*	*GDP2*	*IND*	*URB*	ECT_{t-1}
LNCO2	-	0.877	1.367	1.874	1.204	
		(0.348)	(0.242)	(0.171)	(0.272)	-
GDP	1.324	-	3.795*	2.152	74.003***	0.02***
	(0.249)		(0.051)	(0.142)	(0.000)	(-8.481)
GDP2	1.323	1.411	-	1.799	120.937***	-0.09***
	(0.250)	(0.234)		(0.179)	(0.000)	(-10.84)
IND	0.178	1.245	0.470	-	7.012***	-
	(0.672)	(0.264)	(0.492)		(0.008)	
URB	0.179	1.310	1.663	0.723	-	-0.017*
	(0.679)	(0.252)	(0.197)	(0.395)		(-1.938)

Note. *** and * indicate the significance level at 1% and 10%.

Source: The authors.

From this table, we deduce unidirectional and bidirectional causalities. There are unidirectional causalities between urbanization and GDP per capita, and between urbanization and industrialization. The causal relationship between urbanization and the variable GDP per capita assumes that urbanization promotes wealth growth. The causal relationship between urbanization and industrialization assumes that strong urbanization leads to the emergence of industrial added value in the urban area. Their values for the lagged error correction terms -0.021 and -0.094 respectively indicate that the shocks experienced by the system converge to the long-run equilibrium at low speeds for the GDP and GDP2 equations of economic growth, but at a low speed. There is therefore a long-run causality from carbon emissions, industrialization and urbanization to economic growth. Similarly, the value -0.017 of the lagged error correction term for the urbanization equation shows that there is a long-run relationship from carbon emissions, industrialization and economic growth to urbanization. Consequently, there is a long-run bidirectional causality between economic growth and urbanization (see table 4). These two variables also play an important role in carbon dioxide emissions in Côte d'Ivoire.

6.2 Stationarity and Cointegration tests

The results of the Zivot-Andrews (ZA) unit root test are shown in Table 5 below.

Table 5. Summary of the Zivot-Andrews stationarity test

Variable	ZA structural break in both the intercept and trend unit root test			
	Level		First difference	
	t-stat	TB	t-stat	TB
LNCO2	-2.4460	2007	-8.1452*	1990
GDP	-3.5949	1980	-7.3977***	1980
GDP2	-4.0641	1980	-7.7108***	1980
IND	-4.1278	1993	-8.4670**	1992
URB	-3.7320	2009	-19.3298***	1980

Note. ***, ** and * indicate the significance level at 1%, 5% and 10%.

Source: The authors.

According to the results of the ZA unit root test taking into account the breaks given in Table 5, all variables are stationary in first difference I(1) with a structural break in both ordinate and trend. The I(1) variables do not generally provide us with long-run information, unlike the I(0) variables. To establish a long-run relationship between the variables in our model, we will study cointegration. Tables 6 and 7 below show the results of the Johansen (1988) and Pesaran et al. (2001) cointegration tests.

Table 6. Summary of Johansen cointegration test

Number of equations for assumed cointegration	trace statistic	critical value at (5%)	Eigenvalue statistics	critical value at (5%)
None	82.81028	60.06141	32.92551	30.43961
At most 1	49.88477	40.17493	25.91399	24.15921
At most 2	23.97077	24.27596	12.34159	17.79730

Source: The authors.

The first row of Table 6 shows values for the trace and maximum likelihood statistics above the 5% critical values. This leads us to the existence of a cointegrating relationship between the variables. The second line gives the same information, namely that the trace and maximum likelihood statistics are greater than the critical values at 5%. However, we accept the H0 hypothesis of no cointegration in row three, as the values of the trace and maximum likelihood statistics are below the 5% critical values. Ultimately, we conclude that the results in Table 6 reveal the existence of at least one cointegrating relationship between the variables, meaning that the variables in the model are all integrated. The results in Table 7 confirm the existence of a cointegrating relationship between the series, as the calculated F-stat value of 3.230 is greater than the upper bound of 3.09 at the 10% significance level (rejecting the H0 hypothesis of no cointegration). In other words, we can estimate the long-run effects between the variables in the model.

Table 7. Results of the cointegration test of Pesaran et al. (2001)

Model	*LNCO2=f (GDP, GDP2, IND, URB)*	
F-statistics	3.230	
Level	*Lower bounds*	*Upper bounds*
10%	2.2	3.09
5%	2.56	3.49
1%	3.29	4.37

Source: The authors.

The optimal lag structure is pre-selected from the minimum SIC value; the ARDL model (1,0,0,0,0,) is the optimal model (see Figure 1).

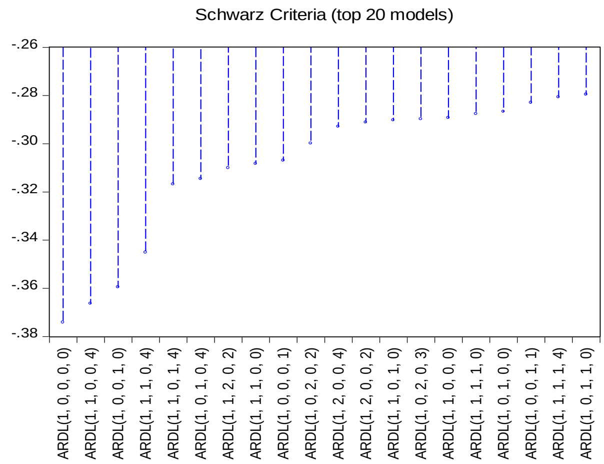

Figure 1. Optimal lag with SIC information criterion

Source: The authors.

6.3 Estimation Results and Interpretation

The results of the short-run and long-run estimates in Table 8 below show that the coefficient associated with the recall force is negative (-0.656153) and significant at the 1% level, so there is indeed an error-correction mechanism. In other words, in the long-run, the imbalances between the variation in the logarithm of CO2 emissions and the explanatory variables GDP, GDP2, IND and URB offset each other, so that the series have similar evolutions. Furthermore, our results also show that in both the short and long-run, the signs of the GDP per capita terms significantly validate the existence of an inverted U-shaped environmental Kuznets curve. The results show that the long-run variations in income significant at the 5% threshold for CO2 emissions, with 3.564705 as the value for GDP and -0.975851 as the value for GDP2, are lower than the short-run variations significant at the 1% threshold for CO2 emissions, with 4.274255 as the value for GDP and -1.086913 as the value for GDP2. From this result we can say that increasing GDP per capita in Côte d'Ivoire decreases CO2 emissions. This result confirms the environmental Kuznets curve (EKC) hypothesis that growth, by raising the level of per capita income in the country, leads to an improvement in environmental quality. This result is in line with the findings of Keho (2015), Raheen and Ogebe (2017) and Koilo (2019), which validate the EKC hypothesis between economic growth and CO2 emissions.

The results show that the estimated coefficients of the income variable are significant and respectively positive and negative in the short-run at the 1% threshold and in the long-run at the 5% threshold. This indicates the existence of an inverted U-shaped Kuznets relationship for CO2 emissions. The gradual increase in per capita income first leads to an increase in CO2 emissions, and then to a decrease. The long-run turning point is given by $gdp* = (-3.564705/2*(-0.975851))$, i.e. $gdp* = 1.826459$ thousand US dollars. This value lies between the minimum value of GDP, which is equal to 1.138665, and its maximum value, which is equal to 2.471015 (see Table 2). In other words, the turning point has been reached for Côte d'Ivoire, according to our estimation data. Consequently, Côte d'Ivoire is on the second slope of the curve, where the population has become aware of and demands good environmental quality.

Furthermore, our results show that in the long-run, the urban population has a positive and significant effect at the 1% threshold on CO2 emissions in Côte d'Ivoire. This result confirms the high correlation coefficient between urbanization and CO2 emissions shown in Table 3. Any 1% increase in urban population increases CO2 emissions by 0.080%. In our view, this result could be explained by the fact that, Côte d'Ivoire being a developing country, increasing urbanization and population growth are accompanied by the development of energy-producing industrial sectors and the development of hydrocarbon-intensive transport, thus contributing on a large scale to CO2 emissions. This result is in line with the findings of Alam et al. (2007), who assessed the impact of urbanization on the CO2 emission rate in Pakistan using the STIRPAT model and found a positive relationship between the degree of urbanization and the CO2 emission rate. Poumanyvong and Kaneko (2010), analyzing the impact of urbanization on minimum energy use and CO2 emissions for 99 countries covering the period 1975 to 2005, also demonstrated that urbanization positively influences CO2 emissions for all country groups. But they find that the impact is more pronounced in middle-income countries than in other country groups.

Table 8. ARDL model test results

Independent variables	dependant Variable: LNCO2	
	Coefficient	p-value
Long-run results		
Constant	3.392904**	0.0381
GDP	3.564705**	0.0204
GDP2	-0.975851**	0.0228
IND	-0.045592	0.1400
URB	0.080268***	0.0000
Short-run results		
Constant	1.869819**	0.0494
D(GDP)	4.274255***	0.0050
D(GDP2)	-1.086913***	0.0044
D(IND)	-0.001679	0.9139
D(URB)	0.026857	0.5317
ECT(-1)	-0.656153***	0.0000
R-squared	0.802007	
Adjusted *R*-squared	0.777258	
F-statistic	32.40546***	

Note. *** and ** indicate the significance level at 1% and 5%.

Source: The authors.

6.4 ARDL Model Diagnostics Tests

In Table 9 below, we summarize the tests that help diagnose the estimated ARDL model.

Table 9. ARDL model diagnostic tests

Diagnostic test	Tests	p-value
Normality	Jarque-Bera	0.88
Serial correlation	Breusch-Godfrey	0.95
Heteroscedasticity	White	0.23
	ARCH	0.24
Functional form	Ramsey (Fisher)	0.65

Source: The authors.

The null hypothesis is accepted for all tests, so the model is statistically validated (see Table 9). The estimated ARDL (1, 0, 0, 0, 0) model is globally good, as the F-statistic shows that the model is globally significant (See Table 8). Figures 2 and 3 also show that the CUSUM and CUSUM Squares test statistics, after introducing a dummy variable to account for the break in the explained variable in 1990, evolve well within the confidence interval at the 5% threshold; we conclude in favor of parameter stability. The model is therefore structurally and punctually stable.

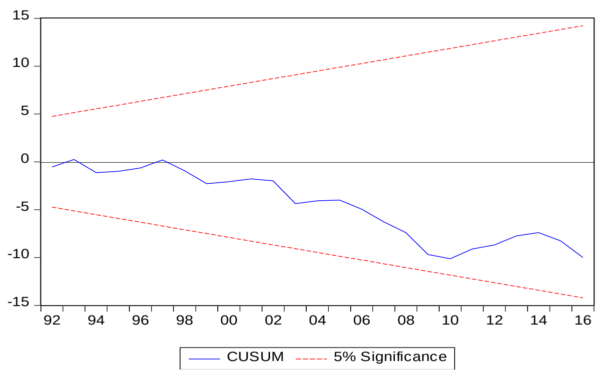

Figure 2. Graph of CUSUM

Note. the straight lines represent critical bounds at à5% significance level.

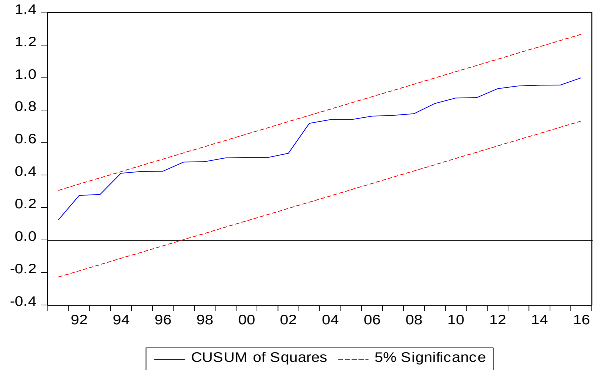

Figure 3. Graph of CUSUM Square

Note. the straight lines represent critical bounds at à5% significance level.

Source: The authors.

6.5 Variance Decomposition Method

The results of the variance decomposition approach are shown in Table 10 below. In the short-run, i.e. in the third year, impulse or innovation or the shock to CO2 emissions explains 87.60% of the variation in CO2 (clean shock); the shock to GDP can cause 0.77% of CO2 emissions. Also, the industrialization shock (IND) can cause 4.30% of CO2 emissions, and the urbanization shock (URB) can cause 5.49% of CO2 emissions. In the long-run, i.e. in the tenth year, the shock to CO2 emissions explains 56.08% of the variation in CO2 (clean shock); the shock to GDP can cause 15.00% of CO2 emissions. Also, the industrialization shock (IND) can cause 5.34% of CO2 emissions, and the urbanization shock (URB) can cause 15.91% of CO2 emissions. Over the long-run, the contribution of GDP to CO2 emissions increases from 0.77% to 15.00%. The contribution of industrialization (IND) and urbanization (URB) to CO2 emissions also increases, from 4.30% to 5.34% and from 549% to 15.91% respectively. The overall results underline the fact that economic growth, industrialization and urbanization are major contributors to CO2 emissions in Côte d'Ivoire.

Table 10. Results of the variance decomposition method

Variance decomposition of LNCO2						
Period	S.E.	LNCO2	GDP	GDP2	IND	URB
1	0.16298	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.19159	92.91013	0.685983	0.271195	0.801649	5.331047
3	0.19972	87.60576	0.779771	1.813826	4.301253	5.499386
4	0.20801	80.81059	1.730260	5.119011	7.051111	5.289031
5	0.21328	76.86960	3.187309	7.043125	7.073199	5.826762
6	0.21839	73.34123	5.723171	7.926007	6.748337	6.261255
7	0.22508	69.22923	8.495413	8.040795	6.366484	7.868078
8	0.23343	64.66267	11.29225	7.936869	5.926995	10.18122
9	0.24279	60.03174	13.46320	7.766458	5.556830	13.18177
10	0.25146	56.08999	15.00132	7.653816	5.343438	15.91144
Variance decomposition of GDP						
Period	S.E.	LNCO2	GDP	GDP2	IND	URB
1	0.05097	19.99084	80.00916	0.000000	0.000000	0.000000
2	0.10791	10.41345	51.12132	2.152137	1.114250	35.19885
3	0.16156	7.882041	48.15920	7.829983	2.901891	33.22688
4	0.20375	7.065482	46.43225	11.03843	2.618631	32.84520
5	0.23191	6.714341	47.12577	13.10966	2.272307	30.77792
6	0.24989	6.538960	47.58393	13.94942	1.996288	29.93141
7	0.26074	6.419299	48.02472	14.28085	1.848317	29.42681
8	0.26701	6.319318	48.18501	14.34428	1.771792	29.37960
9	0.27033	6.235663	48.24341	14.34896	1.741903	29.43007
10	0.27183	6.180149	48.23215	14.34004	1.733538	29.51412

Variance Decomposition of GDP2						
Period	S.E.	LNCO2	GDP	GDP2	IND	URB
1	0.17514	14.50226	80.25822	5.239517	0.000000	0.000000
2	0.40049	5.397847	42.99738	1.258889	2.377676	47.96821
3	0.60241	3.900536	41.23348	5.563135	5.020607	44.28224
4	0.75426	3.606239	40.46321	8.702208	4.430571	42.79777
5	0.84728	3.552070	41.91066	10.86668	3.831039	39.83955
6	0.90156	3.563485	42.78149	11.73356	3.411502	38.50996
7	0.93058	3.566949	43.42233	12.05278	3.205995	37.75195
8	0.94506	3.549128	43.65847	12.10441	3.110193	37.57780
9	0.95116	3.521942	43.73533	12.10485	3.076126	37.56175
10	0.95301	3.508250	43.72822	12.09700	3.069351	37.59718
Variance Decomposition of IND						
Period	S.E.	LNCO2	GDP	GDP2	IND	URB
1	1.21628	2.869008	0.047078	2.981925	94.10199	0.000000
2	1.52392	5.306004	1.096612	1.928934	80.66784	11.00061
3	1.70625	12.79269	0.915485	2.280688	72.89368	11.11746
4	1.78418	15.91359	0.946203	2.332209	67.24627	13.56172
5	1.80258	16.61680	1.509237	2.358305	65.93512	13.58054
6	1.81315	16.45829	1.851154	2.342462	65.63220	13.71590
7	1.81776	16.41462	2.085522	2.344483	65.47907	13.67630
8	1.81937	16.46224	2.121358	2.347319	65.39463	13.67445
9	1.81990	16.47972	2.120920	2.346093	65.35687	13.69640
10	1.82213	16.44009	2.189119	2.340433	65.19688	13.83348
Variance Decomposition of URB						
Period	S.E.	LNCO2	GDP	GDP2	IND	URB
1	0.17721	0.254094	9.871623	6.910185	2.629855	80.33424
2	0.38397	0.400253	11.86733	1.886482	4.997827	80.84811
3	0.58802	0.368868	13.38823	0.854524	5.632940	79.75544
4	0.76151	0.399531	14.42421	0.717466	5.502813	78.95598
5	0.89991	0.526007	14.73213	0.649282	5.191203	78.90138
6	1.00735	0.778451	14.37451	0.539641	4.932880	79.37452
7	1.09069	1.194227	13.53467	0.472875	4.771834	80.02639
8	1.15627	1.808112	12.47274	0.549405	4.691859	80.47788
9	1.20937	2.634763	11.44748	0.835368	4.654304	80.42808
10	1.25420	3.656532	10.67787	1.361140	4.621002	79.68346

Source: The authors.

As an alternative to the variance decomposition method, we use the impulse response function, which shows how long and to what extent the dependent variable reacts to the shock coming from the independent variables. The amplitude takes into account the effects of the shock over 10 years, which represents the time required for the variables to return to their long-run levels. The results in Figure 4 below show that the response of economic growth to CO2 emissions increases initially, peaks in the third year and then begins to decline after the fourth temporal horizon. This presents the phenomenon of the environmental Kuznets curve, or the inverted U-shaped relationship between economic growth and CO2 emissions. On the other hand, the response of GDP squared by remaining in the negative zone confirms the inverted-U relationship and indicates that increasing GDP per capita in Côte d'Ivoire reduces CO2 emissions. A shock to industrialization initially reduces CO2 emissions up to the third period, but from the fourth year onwards the trend is upwards, although remaining in the negative zone. As a result, shocks to industrialization will have a positive impact on CO2 emissions. A shock to urbanization initially reduces CO2 emissions until the second period. Beyond the second period, there is an increase for the remainder of the period. As a result, shocks to urbanization will have a positive impact on CO2 emissions. The results of the impulse response function test confirm those of the variance decomposition test, i.e. that economic growth, industrialization and urbanization play a major role in CO2 emissions in Côte d'Ivoire. However, the existence of the environmental Kuznets curve indicates that increasing wealth in Côte d'Ivoire reduces CO2 emissions in the long-run.

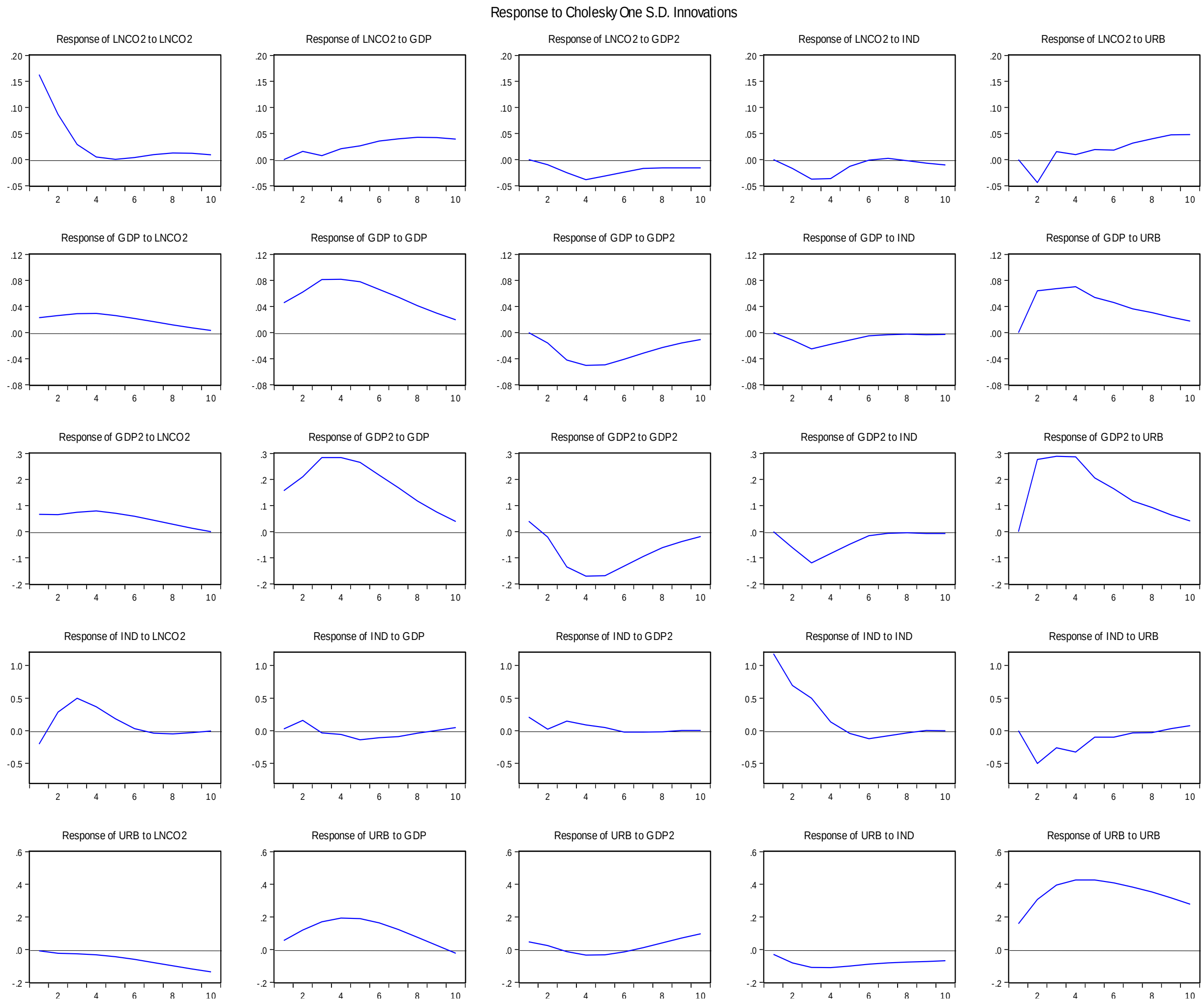

Figure 4. Impulse response function

Source: The authors.

7. Discussion

This study deals with the empirical analysis between CO2 emissions and economic growth by incorporating industrialization and urbanization as potential determinants of the CO2 emissions function in the case of Côte d'Ivoire over the period 1970-2016. We applied the unit root test of Zivot and Andrews (1992) with an endogenous break and the long-run relationship between the variables is studied by applying the cointegration test of Johansen (1988) and that of Pesaran et al. (2001) called ARDL bound test. The causal relationship between economic growth, CO2 emissions, urbanization and industrialization are examined by applying the Granger VECM causality approach.

Also, the results of the Impulse response function test and those of the variance decomposition test show that economic growth, industrialization and urbanization contribute strongly to CO2 emissions in Côte d'Ivoire. Although the existence of the environmental Kuznets curve indicates that increasing wealth in the country will reduce CO2 emissions in the long-run, it should be noted that if nothing is done in terms of environmental and social policies (increasing wealth per capita, for example), the increase in CO2 emissions could lead to a rise in temperature, ecosystem disruption and adverse effects on human health.

According to the results of our study, the ARDL bound test approach indicates that there is cointegration between the variables and a long-run relationship between economic growth and CO2 emissions. The existence of a causal relationship between economic growth and CO2 emissions is confirmed by Granger's VECM causality approach. The estimated ARDL model confirms in both the short and long-run that the signs of the GDP per capita terms significantly validate the existence of an inverted U-shaped environmental Kuznets curve. There is therefore a EKC between economic growth and CO2 emissions in Côte d'Ivoire.

Moreover, in the long-run, the turning point is 1.826459 thousand US dollars, and this point has been reached in the case of Côte d'Ivoire according to the data in our study. Based on these results, we suggest that Côte d'Ivoire implement specific and sustained policies to increase GDP per capita in order to improve environmental quality. The Ivorian authorities must implement specific policies to significantly reduce carbon dioxide emissions. To do so, we suggest a sound carbon pricing policy as well as strategies for the promotion and development of clean and renewable energies. With regard to the carbon pricing policy or carbon tax, we note that an environmental tax already exists in Côte d'Ivoire, although it does not currently include taxation of greenhouse gas (GHGs) emissions. For example, in 2016, there was an attempt was made to take into account and project scenarios for potential carbon tax revenues, based on a psychologically acceptable price per ton of CO2.The starting carbon price was 1,000 CFA francs and the more ambitious price was 2,500 CFA francs. With this projection, cumulative revenues from the carbon tax would be 493.5 billion CFA francs and 1,233.7 billion CFA francs respectively (Ministère de l'Environnement et du Développement Durable, 2016). This amount could have contributed to financing adaptation and CO2 emission reduction measures. As for the promotion and development of clean and renewable energies, this will require the necessary institutional regulations to be put in place. Regulatory instruments will thus provide incentives for the spread of clean technologies and help reverse the trend towards rising CO2 emissions.

The significantly positive relationship between urbanization and CO2 emissions in Côte d'Ivoire could be explained by the fact that urbanization favors the development of energy-producing industries and hydrocarbon-intensive transport. The appropriate choice of instruments to reduce CO2 emissions is, however, a complex political decision. However, governments need to promote major investments in clean energies, while encouraging the use of butane gas in homes in urban areas, for example.

Acknowledgments

The authors would like to thank the researchers of the Laboratory for Law, Economics and Management (LADEG) for very useful comments on earlier versions of this paper.

Authors Contributions

Dr. BGJJI, Dr. JBT and Dr. YJEK were responsible for study design and revising. Dr. JBT and Dr. YJEK were responsible for data collection. Dr. BGJJI and Dr. JBT drafted the manuscript and Dr. BGJJI, Dr. JBT and Dr. YJEK revised it. All authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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