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Ambivalent causal relationship between economic growth and carbon dioxide emissions in Benin

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Abstract

The paper aims to verify the ambivalent causal relationship between economic growth and carbon dioxide emissions. The data used were obtained from the World Development Indicators database for the period of 2000-2023. The simultaneous equation model was used with three-stage least squares (3SLS). The results revealed that gross domestic product increased CO2 emissions by 0.787 and that CO2 emissions decreased gross domestic product by 0.375 at the threshold of 1%. However, to achieve growth in terms of environmental protection in Benin, it is necessary to invest more in ecotourism, renewable energy consumption, and activities capable of increasing the capacity for CO2 absorption and internal carbon storage.

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1. Introduction

The Industrial Revolution of the 19th century essentially leads to the quest of economic growth. Thus, the Gross National Product (GNP) is often considered an indicator of country performance. However, the report of Stiglitz Commission highlighted the shortcomings of the GNP as an indicator for measuring performance and progress. It stressed that the GNP has "blinded and made people collectively insensitive to the excesses of the development model, such as social, ecological, economic and financial crises." According to Crifo et al. (2009), the conclusions of this report are particularly pessimistic and highlighting the immense environmental crisis caused by global warming. In addition to the economy and society, a third aspect, namely, the environment, has been neglected. However, economic development can be sustainable only if it is harmoniously aligned with sustainable development goals. Therefore, the major concern of greenhouse gases (GHGs) emissions has spread in developed countries as well as in developing countries since the publication of the Meadows' report in 1972. This awareness led to the organization of several major international meetings. These include i) the Rio Earth Summit in 1992 and the United Nations Framework Convention on Climate Change, which led to the Kyoto Protocol Agreement, that entered into force in 2005, and ii) the United Nations Conference on Climate Change in Paris in 2015 (COP21), which resulted in the Paris Agreement, also called the International Climate Agreement. It aims to struggle against climate change by restricting global warming to less than 2 degrees Celsius above preindustrial levels and by limiting the increase in temperatures to 1.5 degrees Celsius. According to the "Intergovernmental Panel on Climate Change" (IPCC, 2007), carbon dioxide is the main greenhouse gas responsible for global warming. Economic activities such as agriculture, industrial production, energy consumption and transport are the main sources of GHG emissions. Liu et al (2024) further clarified this observation very recently by indicating that apart from CO2 emissions, the following greenhouse gases are methane and nitrous oxide, part of whose global emissions come from agriculture (60% and 40% respectively).

In Benin, the energy and agriculture sectors emit the majority of GHG emissions, contributing up to 27% and 69%, respectively, in 1990 and 53% and 41%, respectively, in 2015, according to the Third National Communication on Climate Change (Ahlonsou et al*.,* 2019). According to the same source, CO2 is the most emitted GHG and increases to nearly 30.2% between 1990 and 2023. An increase in CO2 emissions contributes to the increase in global temperatures, the melting of glaciers, rising sea levels and other extreme climate events. This problem raises complex and contradictory issues. For Cooper (2002) and Romer (1993), economic development is considered essential for improving the living conditions of populations, reducing poverty and promoting social progress. However, in the long run, Vissin et al., (2003) and the IPCC (2007) demonstrated that the detrimental effect of the environment outweighs growth.

The effects of economic growth on carbon emissions are the subject of much debate in the literature and various trends are observed. Several studies have revealed the "inverted U-shape" relationship between the two quantities (Grossman and Krueger, 1995; Shahbaz et al., 2013; Aboagye, 2017; Weimin et al., 2022; Sazuli, 2025). This situation confirmed the Environmental Kuznets Curve (EKC) hypothesis. This trend has been recently validated in Africa (Agyeman et al., 2022; Mignamissi et al., 2024). Mikayilov et al. (2018) showed that the link between economic growth and environmental degradation didn't validate the EKC hypothesis. For them, GDP per capita increases CO2 emissions without any threshold effect. Other researchers' findings corroborate these authors results (Asiedu Ampomah et al., 2021; Shahbaz et al., 2019; Adams and Acheampong, 2019). Other tendencies specifically revealed "N"-shaped linking (Awan and Azam, 2021; Liu et al., 2020).

By checking economic growth determinants in Pakistan, it appears, among other things, that CO2 emissions have a positive impact on economic growth (Abbasi et al., 2021). Androniceanu and Georgescu (2023) also showed that carbon emissions have had a strong and positive impact on economic growth. Other recent researches have revealed the same trend (Madaleno and Nogueira, 2023; Pradhan et al., 2024)

One of the main questions that then arises is the following one: Is there any ambivalent causal connection between economic growth and carbon dioxide (CO2) emissions? Given that there is no zero pollution in the production process, it appears necessary to appreciate, on the one hand, how economic growth can contribute to CO2 emissions and, on the other hand, whether causality in the opposite direction is observed. Moreover, Dogan and Aslan (2017) tested the ambivalent relationship between economic growth and the environment via the "Granger causality test". They then studied the relationship between CO2 emissions, GDP, energy consumption and tourism over the period of 1995-2011 in twenty-five (25) countries of the European Union. They demonstrated that energy consumption contributes to an increase in CO2 emissions, whereas GDP and tourism mitigate CO2 emissions. The "Granger causality test" reveals a two-way relationships between CO2 emissions and economic growth. The limitation of their study is that it does not make it possible to identify the explanatory factors of the ambivalent causal links among environment and economic growth. Ganda and Panicker (2025) found a bidirectional causality between GDP and CO2 emissions, starting from a panel of Sub-Saharan African countries with which they applied the D-H causality test.

The main findings of this research reinforce empirical literature in the topic. Then, the CO2 increasing from production process is be revealed. The increase of CO2 emissions also influences negatively the economic growth. It's means that to achieve economic growth with the reduction of CO2 emissions becomes a challenge.

The remainder of this paper is structured as follows. Section 2 presents the empirical methodology. Section 3 addresses the data and findings. Section 4 provides the conclusion.

2. Empirical methodology

2.1. Specification of the models

The structural approach to determine the link among growth and the environment, which was initially described by Erlich and Erlich (1981), is the theoretical model for this research. In its structural form, their model is defined as follows:

$$I = P.A.T \tag{1}$$

where I is the pressure on the environment, P is the size of the population, A is the level of consumption per capita and T is an index of technology.

The weakness of their model is that it is only structural: it obscures the fact that these three variables are all endogenous in relation to each other, a fortiori in a context. In a context of ambivalent causal relationships, suspected endogeneity is a source of simultaneity (Acemoglu et al., 2001) . It is therefore difficult to determine whether economic growth determines the environment or whether the opposite occurs (Navatte, 2016).

Furthermore, to correct these criticisms, a simultaneous equation model was proposed to correct not only the endogeneity problem but also the ambivalent causal link sought between CO2 and GDP. These simultaneous equation models are written as follows:

$$\begin{cases} CO_{2t} = \beta_0 + \beta_1 l(GDP)_t + \beta_{i-2} X_t + \varepsilon_{1t} \\ l(GDP)_t = \alpha_0 + \alpha_1 CO_{2t} + \alpha_{j-2} Y_t + \varepsilon_{2t} \end{cases} \quad (2)$$

From the carbon dioxide emission equation, CO_{2t} represents the emission of carbon dioxide (CO2); β_0 represents a constant; β_1 represents the natural logarithm of the gross domestic product parameter (variable of interest); β_{i-2} represents the vector of parameters of the explanatory variables; X_t represents explanatory variables' vector; and ε_{1t} represents the error term. Similarly, for the growth equation, DGP_t is the gross domestic product; α_0 is the constant; α_1 is the carbon dioxide parameter (variable of interest); α_{j-2} is the vector of parameters of the explanatory variables; Y_t is explanatory variables' vector; ε_{2t} is the error term; and *l* is the natural logarithm.

In its functional form, the simultaneous equation model becomes:

$$\begin{cases} CO_{2t} = \beta_0 + \beta_1 l(GDP)_t + \beta_2 l(TOUR)_t + \beta_3 REC_t + \beta_4 FDI_t + \varepsilon_{1t} \\ l(GDP)_t = \alpha_0 + \alpha_1 CO_{2t} + \alpha_2 l(TOUR)_t + \alpha_3 FDI_t + \alpha_4 l(POP)_t + \alpha_5 (Trade)_t + \varepsilon_{2t} \end{cases} \quad (3)$$

where β_0 and α_0 are model constants; β_i are *i=1,2,3,4* and α_j are *j=1,2,3,4,5* are explanatory variables' coefficients of the simultaneous equation model; ε_{it} is the error term, which is centered random variable $E(\varepsilon_{it}) = 0$, ∀ ; and *i=1, 2* and are the indices of the temporal dimension (t = 2000....2023). The model variables include:

$l(GDP)_t$: logarithm of Gross Domestic Product per capita (constant 2015 US $) ,
$l(TOUR)_t$: logarithm of International Tourism (number of arrivals) ,
REC_t: Renewable Energy Consumption (% of total final energy consumption) ,
FDI_t: Foreign Direct Investment, net inflows (% of GDP) ,
CO_{2t}: CO2 emissions (metric tons per capita),

$(Trade)_t$: Trade (% of GDP), and

$l(POP)_t$: logarithm of Population

2.2. Identification of the simultaneous equation model and estimation technique

We note two conditions for identifying a system with simultaneous equations: the order condition and the rank condition. The rank condition determines whether the equation in question is identified. The order condition determines whether the equation is exactly identified or over-identified.

The rank condition is often complex. The order condition is used in this research. The order condition is defined by $K - k \geq m - 1$. *M* = endogenous variables' number in the model; *K* = exogenous variables' number in the model; *m* = endogenous variables' number in each equation; *k* = exogenous variables' number in each equation.

Under these order conditions, three cases are possible: i) if $K - k > m - 1$, the equation is over-identified; ii) if $K - k = m - 1$, the equation is identified; and iii) if $K - k < m - 1$, the equation is under-identified.

Furthermore, when the equation is under-identified, there is no estimation technique. Therefore, equation (1) contains $k=4$ and $m=1$. Total number of exogenous variables of the system is $K=7$, and that of the endogenous variables is $M=2$. Let $K\text{-}k=3$ and $m\text{-}1=0$. We see that $K-k>m-1$, i.e., 3 > 0. Thus, the first equation of the system is over-identified.

The second equation of the system contains $k=5$ and $m=1$. Exogenous variables' total number of the system is $K=7$, and that of the endogenous variables is $M=2$. Let $K\text{-}k=2$ and $m\text{-}1=0$. We see that $K-k>m-1$, that is, 2 > 0, the second equation of the system with simultaneous equations is also over-identified. Thus, each equation is over-identified, and the model is over-identified.

Notably, in the literature, limited information methods and full information methods are used to estimate a simultaneous equation model (Yai et al., 2021; Cameron and Trivedi, 2009). The literature recommends the use of full information methods estimated by three-stage least squares (Camron and Trivedi, 2009) when the model is over-identified.

3. Data and empirical findings

3.1. Data

This study is based on Benin. The data are quantitative and annual and cover the period of 2000-2023. These data come from the "World Development Indicators" (WDI, 2024). In this study, the data are analyzed via descriptive analysis and explanatory analysis. Descriptive analysis' purpose is to structure and represent the information contained in the data to present the evolution of GHG components by sector of activity. Explanatory analysis refers to econometric modeling.

3.2. GHG emissions in Benin by sector and the CO2 trend in Benin's GDP

Based on the data from the Ministry of Living Environment and Sustainable Development (MCVDD, 2022), the total direct GHG emissions (without Forestry and other Land Uses (FATs)) in Benin in 2015 were estimated to be 11,752.18 gigagrams CO2 equivalent (Gg CO2 eq), the universal unit of comparison. The energy and agriculture sectors emitted the majority of emissions, contributing 27% and 69%, respectively, in 1990 and 53% and 41%, respectively, in 2015 (Figure 1.a). The individual contributions of the waste sector and industrial processes were estimated to be 2% in 1990 and 3% in 2015. This strong contribution of the energy sector to total direct GHG emissions excluding the FAT in 2015 could be explained in particular by the high consumption of gasoline (sometimes lead) and diesel in transport. Concerning the waste sector in 2015, the largest contributor to direct GHG emissions was the category of treatment and discharge of wastewater (88%), whereas industrial' emissions processes sector was generated by the cement industry (56%) and the use of ozone-depleting subsistence fluorinated substitutes (44%).

Considering the FAT sector, total emissions and absorptions are estimated in 2015 at 34,937.03 Gg CO2 eq and -27,144.66 Gg CO2 eq, respectively, i.e., a net emission of 7,792.37 Gg CO2 eq. The FAT sector is entirely responsible for CO2 absorption and represents the principal source of direct GHG emissions (66%) and indirect GHG emissions (74%) (Figure 1 a and Figure 1 b).

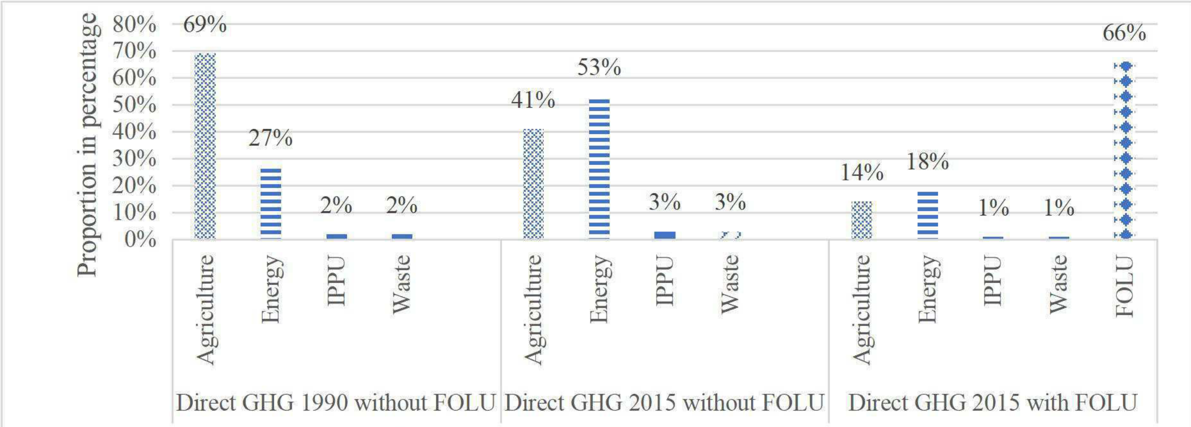

Figure 1.a. Contribution of each sector to direct GHG emissions

Source: Author, based on MCV&DD data, 2022

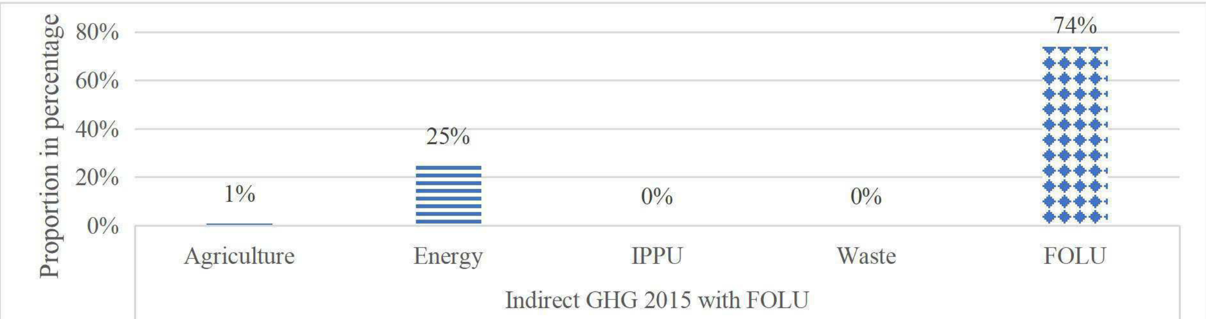

Figure 1.b. Contribution of each sector to indirect GHG emissions

IPPU: Industrial Processes and Products Use; FOLU: Forestry and Other Land Use

Figure 1: Comparative distribution of annual GHG emissions per sector

Source: Author, based on MCV&DD data, 2022

From figure 2, the analysis of the comparative trend of CO2 emissions to GDP reveals that as GDP increases, direct CO2 emissions tend to increase (especially between 2016 and 2020). However, we note that in years when CO2 emissions are high, the GDP increases less. This finding suggests that CO2 has a negative effect on growth. This effect is later verified by the ambivalent causality relationship sought. From 2021 onwards, we observe a downward trend in CO2 emissions while the gross domestic product maintains the upward trend. This situation suggests a semblance of a reversal in the trend in CO2 emissions from 2018. This observation could be confirmed or not after the estimation of the chosen econometric model.

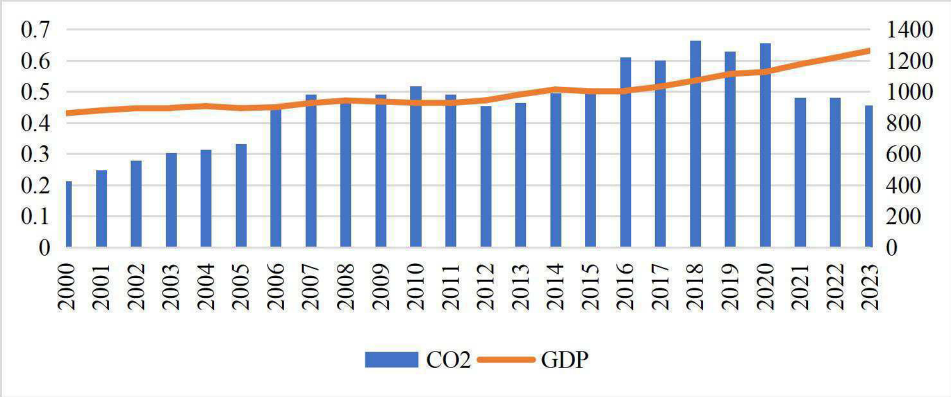

Figure 2: Comparative trend of Benin's CO2 emissions and GDP

Source: Author, based on WDI, 2024

3.3. Durbin and Wu–Hausman endogeneity tests

Both the Durbin (score) and the Wu-Hausman tests reject the null hypothesis of exogeneity at the 1% level of significance. The Durbin test yielded a chi-square statistic of 11.58 (p = 0.0007), and the Wu-Hausman test reported an F-statistic of 17.71 (p = 0.0005). These results confirm the presence of endogeneity and justify the use of a simultaneous equation modeling approach, such as the Three-Stage Least Squares (3SLS) method, for consistent estimation.

Table 1: Durbin and Wu–Hausman endogeneity tests

Test	Test Statistic	Degrees of Freedom	p-value	Decision (1%)	Conclusion
Durbin (score) Test	$\chi^2 = 11.5797$	df = 1	0.0007	Reject *H_0	Evidence of endogeneity
Wu-Hausman Test	F = 17.7141	df = (1, 19)	0.0005	Reject H_0	Variable is endogenous

*H0: Variables are exogenous

Source: Author

3.4. Overall significance of the "simultaneous equation model"

Taken individually, each of the two equations of the "simultaneous equations" system suffers from endogeneity (Table 2). Consequently, using the "simultaneous equations model" makes it possible to address endogeneity and verify reciprocal causal relationships.

In the "simultaneous equation model" (Table 2), each of the equations has a chi-square probability of 0.0000, which is less than 1%. This indicates that the "simultaneous equation model" is significant overall.

Table 2: Overall significance tests of the models without and with the "EKC hypothesis"

Simultaneous equations	Observations	Parameters	Chi-square	Probability
CO2	24 (24)	4 (5)	289.11*** (271.68***)	0,0000 (0,0000)
lGDP_c	24 (24)	5 (5)	1142.45*** (1137.31***)	0,0000 (0,0000)

(.) Information on the overall model significance test with EKC verification; legend: ***p< 0,01, **p< 0,05, *$p < 0,1$; *lGDP_c is lGDP centered*

Source: Author

3.5. Estimation results of the "simultaneous equation model" without the threshold effect

According to the results obtained from the equation of determinants of CO2 emissions, the natural logarithm' coefficients of the gross domestic product are positively significant at the 1% threshold. This means that a 1% increase in GDP leads to an increase in CO2 emissions of 0.787 to 1.057 in each of the respective models without CEK verification and with CEK verification. The coefficients associated with tourism are 0.046 and 0.044. They are statistically significant at the 10% threshold. This indicates that when the tourist arrivals' number increases by 1% in Benin, carbon dioxide (CO2) emissions increase by 0.046 metric tons and 0.044 metric tons, respectively. The coefficients associated with renewable energy consumption in each of the two models are -0.013 and -0.009, which are statistically significant at the 1% probability level. This indicates that a one unit increases in "renewable energy consumption", CO2 emissions decrease by 0.013 metric tons and 0.009 metric tons, respectively.

From the results obtained from the equation determining economic growth, taking GDP as a dependent variable, we can see that the p-value associated with the CO2 coefficients is equal to 0.000 below the 1% threshold in both models, so they are significant. In addition, the coefficients are negative, which indicates that CO2 emissions have a negative influence on GDP (-0.375 and -0.379 respectively). The coefficients associated with tourism are 0.0626 and 0.0625 respectivly, and statistically significant at the 1% probability level. This finding indicates that when tourism increases by 1%, the gross domestic product increases by US$0.0626 and US$0.0625 respectively. The coefficients associated with population are 0.801 and 0.803 and statistically significant at the 1% probability level. This indicates that when Benin's population increases by one unit, the gross domestic product increases in each of the two models by US$0.801 and US$0.803, respectively.

Table 3: Simultaneous equation model of ambivalent causal links between CO2 emissions and economic growth

Model	**Without EKC checking**			**With EKC checking**		
Carbon Dioxide Equation	**Coefficients**	**Standard Error**	**P value**	**Coefficients**	**Standard Error**	**P value**
lGross Domestic Product Centered	0.787***	0.092	0,000	1.057***	0.236	0.000
lGDP Centered square	-	-	-	-2.522	1.958	0.198
lTourism	0.046*	0.025	0,072	0.044*	0.026	0.094
Foreign Direct Investment (% of GDP)	0.002	0.011	0,894	-0.004	0.012	0.760
Renewable Energy Consumption	-0.013***	0.001	0.000	-0.009***	0.002	0.000
Constant	0.549*	0.306	0.073	0.4481	0.328	0.171
Gross Domestic Product Equation	**Coefficients**	**Standard Error**	**P value**	**Coefficients**	**Standard Error**	P value
Carbon dioxide	-0.375***	0.0528	0,000	-0.379***	0.053	0,000
*l*Tourism	0.0626***	0.0105	0,000	0.0625***	0.011	0,000
Foreign Direct Investment (% of GDP)	-0.004	0.0056	0,470	-0.004	0.006	0.450
Trade (% of GDP)	0.001	0.0006	0.111	0.001	0.001	0.104
l population	0.801***	0.035	0,000	0.803***	0.035	0,000
Constant	-13.622***	0.6067	0,000	-13.652***	0.608	0,000

Legend: ***$p < 0,01$, **$p < 0,05$, *$p < 0,1$

Source: Author

3.6. Factors influencing carbon dioxide emissions.

The coefficient associated with gross domestic product is 0.787 and is statistically significant at the 1% probability level. This indicates that gross domestic product growth has a significant influence on carbon dioxide emissions of 0.787. The effect of GDP on CO2 emissions obtained is 9.02 times smaller than the one obtained by Alaganthiran and Anaba (2022) in 20 countries in Sub-Saharan Africa. These figures clearly indicate that there is no growth without environmental degradation in the short or long term, as demonstrated by Balogan (2021) , Adebayo and Rjoub (2022) and Aquils et al. (2022) . Benin's progress towards growth, the promotion of unsustainable agricultural production, the exploitation of natural resources and urbanization will lead to an increase in pollutants and an accumulation of waste that is harmful to the environment.

The coefficient associated with tourism is 0.046 and is statistically significant at the 10% probability level. This indicates that the number of tourist arrivals significantly influences the increase in carbon dioxide (CO2) emissions from 0.046 metric tons. We note that the empirical work related to the effect of international tourism on the environment is mixed. According to the World Tourism Organization (UNWTO, 2008), the contribution of tourism to greenhouse gas emissions is approximately 5% of the total global emissions caused by tourist transport. According to Zhang and Liu (2019), tourism can contribute to the reduction of CO2 emissions when ecotourism is implemented by leaders. In Brazil, the effect of tourism on CO2 emissions reveals an upward trend, to the point where a 1% increase in tourist arrivals leads to an increase of 0.57% and 0.16% respectively in the short and long term (Raihan, 2024). In Benin, the government's efforts in green tourism are therefore a reality in terms of preserving the living environment, modernizing historic towns and developing tourist sites. This could explain the negative effect of international tourism on CO2 emissions in Benin.

The coefficient associated with "renewable energy consumption" is -0.013 and is statistically significant at the 1% probability level. This indicates that "renewable energy consumption" has a significant influence on reducing carbon dioxide (CO2) emissions by 0.013 metric tons. Asiedu et al. (2021) reported that increasing GDP by 1% leads to a reduction in CO2 emissions of 0.64% in the long term. A comparative analysis of the results obtained with those of Asiedu et al. (2021) divulged that there is a difference in the empirical form of the models used.

3.7. Factors influencing gross domestic product growth.

The coefficient associated with carbon dioxide (CO2) emissions is statistically significant at the 1% probability level. This indicates that CO2 emissions have a negative influence on the gross domestic product in Benin. Vissin et al., (2003) and the IPCC (2007) demonstrated that CO2 emissions represent one of the main causes of global warming and a decline in economic activity. Subsequently, Watson and Schalatek (2021) demonstrated that at the global level, Sub-Saharan Africa contributes only 4% to GHG emissions, despite remaining the most exposed to the harmful effects of climate change. As Benin is part of Sub-Saharan Africa, it would be ideal to invest more in reforestation activities to absorb external CO2 emissions. According to the study reported by Ouangbe and Saliou (2023), the country, like Niger, is already investing in the promotion of palm trees to absorb CO2 emissions. In addition to the Gorobiri palm grove and the 400 ha of sexed palm trees planted by the NGO SUBUZE in Malanville, sexing activities are not yet a reality in Benin. Benin would benefit from investing in reforestation of the palm tree type given its ecological advantage in terms of CO2 absorption.

The coefficient associated with tourism is "statistically significant" at the 1% probability level. This indicates that tourism has a significant influence on the increase in gross domestic product of 0.0626. Boer (2015) and Danish and Wang (2018) identify international tourism as a new sector of the economy. Indeed, international tourism increases the overall domestic demand of the visited country. Therefore, it increases GDP growth. This could explain the tourism' effect on the Beninese economy.

The coefficient associated with the population is "statistically significant" at the 1% probability level. This indicates that the population of Benin had a significant influence on the increase in gross domestic product of 0.801. Eighty percent (80%) of the population of Benin is agricultural. However, agriculture is the lifeblood of the Beninese economy through its contribution of nearly 35% to the formation of GDP through the cotton, cashew and soybean sectors (MAEP, 2011; AIC, 2019).

3.8. Checking the EKC hypothesis and the ambivalent causal relationship between economic growth and carbon dioxide emissions

Notably, in the first equation of the simultaneous equation model, the increase in GDP significantly impacts the increase in carbon dioxide emissions. This phenomenon can be explained by the fact that economic development is often associated with an intensification of economic activities, which leads to a greater demand for energy from various sources, such as fossil fuel combustion and coal, oil and natural gas, which are the main sources of CO2 emissions. Likewise, when we take the second equation of the model, the increase in carbon dioxide emissions has a negative and significant effect on GDP. This means that economic activities that produce CO2, in turn, stimulate a decline in economic growth. This leads us to say that there is a reciprocal causal link between economic growth and CO2 emissions. These results verify the Granger causality test performed by Dogan and Alsan (2017). Although the correlation between economic growth and CO2 emissions presents some complexity, a bidirectional causality between GDP and CO2 emissions was be identified (Ganda and Panicker, 2025).

The reciprocal causal link observed between economic growth and CO2 emissions indicates that Benin is in the first phase of the Kuznets curve, where an increase in economic growth leads to an increase in CO2 emissions. Therefore, the results show that the significant positive sign of GDP and the unsignificant negative sign of the square of GDP indicate that the EKC hypothesis not validated. These correct signs of GDP and its square suggest a presumption of this hypothesis. This assumes that the decrease in CO2 emissions has not yet reached the level that could validate the EKC hypothesis. Sazuli (2025) has recently found that the hypothesis is not validated with a U-shaped relationship between sectoral GDP et CO2 emissions in Indonesia case. Ali et al (2023), with a panel of emerging Asian countries, observed that China and Singapore exhibited the inverted U-shape hypothesis, while other countries in the group, such as Japan and South Korea, exhibited the N-shape, and others exhibited no hypothesis. The validation of EKC's hypothesis could be due to the methodology adopted, omission of variables, etc.

Ultimately, the findings of this study corroborate those of several other studies (Ganda and Panicker, 2025; Mignamissi et al., 2024; Ouangbe and Saliou, 2023; Watson and Schalatek, 2021). Thus, strengthening the empirical evidence on the relationship between GDP and CO2 emissions, which constitutes a significant contribution to the economic literature in the field. However, the methodological approach could constitute a limitation of the study. Considering a stochastic approach or taking into account other control variables would significantly strengthen the findings.

4. Concluding remarks

This research aims to verify the ambivalent causal link between economic growth and carbon dioxide emissions in Benin. The data used were obtained from the World Development Indicators database and cover the period of 2000-2023. The simultaneous equation model was estimated via the "three-stage least squares method". The results revealed that gross domestic product increases CO2 emissions by 0.787 at the 1% threshold and that CO2 emissions decrease gross domestic product by 0.375. To achieve growth that respects the protection of the environment, enterprises should invest more in reforestation activities and sustainable agricultural practices in addition to the efforts made by Benin in terms of renewable energy consumption and ecotourism to increase its capacity to absorb CO2. For future studies, the analysis of the ambivalent causal relationship between CO2 emissions and GDP can be conducted by incorporating other control variables or by using a panel of countries; or even by using stochastic approach.

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