

The Carbon Price of Growth: Assessing Sectoral Contributions to the Environmental Kuznets Curve Hypothesis in Cameroon

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ARTICLE INFO	ABSTRACT
Article History Received 29 May 2026 Accepted 29 July 2026 <i>JEL Classifications</i> Q01, Q56 Keywords: CO2 emissions, disaggregated GDP, environmental Kuznets curve, ARDL model, Cameroon	Purpose: This study examines the Environmental Kuznets Curve (EKC) hypothesis in Cameroon, investigating how the relationship between economic growth and CO2 emissions changes when GDP is disaggregated by source (i.e. the primary, secondary and tertiary sectors), rather than being treated as an aggregate measure. The aim is to establish whether the conventional EKC finding obscures divergent growth-emissions dynamics in different sectors, and to derive differentiated policy recommendations accordingly. Design/methodology/approach: The study is based on time-series data from the World Development Indicators and the National Institute of Statistics' National Accounts (INS Comptes Nationaux) for Cameroon. The Autoregressive Distributed Lag (ARDL) bounds testing approach is employed to estimate the long- and short-run relationships between CO2 emissions and GDP. First, total (aggregated) GDP is used, and then GDP is disaggregated by primary, secondary and tertiary sector contributions. Findings: The results of long-run estimation with total GDP show that the EKC hypothesis does exist in Cameroon. The results of long-run estimation with disaggregated GDP present the U relationship between CO2 emissions and GDP that comes from the primary and secondary sectors. But, we have the inverted-U relationship between CO2 emissions and GDP from the tertiary sector. Research limitations/implications: The study is based on a limited sample of country-specific time series, which limits its generalizability. In terms of research implications, policymakers should support eco-friendly and climate-smart farming, while penalising abusive logging to protect primary-sector carbon sinks. They should incentivise low-carbon manufacturing, and shift secondary-sector industries toward hydroelectric and natural gas power. They should leverage tertiary-sector growth through digitalisation of financial and logistical services, and reform trade policy by tightening environmental standards on imported machinery, while investing in low-emission urban transit. Originality/value: This study advances existing knowledge by decomposing Cameroon's GDP into sectoral components, moving beyond the assumption that all economic activities affect the environment uniformly, and offers the empirical precision needed for sector-specific mitigation policies.

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1. Introduction

International discourse and numerous global treaties have centered on the escalating climate change crisis. This sustained focus stems from the profound and multifaceted risks that global warming poses to both human health and the stability of global economic systems.

Reports from the Intergovernmental Panel on Climate Change (IPCC) identify carbon dioxide (CO₂) as a primary driver of global warming (Tamba et al., 2014; IPCC, 2023), highlighting the critical link between climate change and sustainable economic development. A key concept in this context is the Environmental Kuznets Curve (EKC)

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hypothesis, which suggests a functional relationship between economic growth and emission levels (Acheampong, 2018; Mardani et al., 2019). However, empirical validation of this relationship remains inconclusive. While some studies emphasize a unidirectional impact of growth on CO₂ emissions (Zhao et al., 2017; Han et al., 2018), others argue for a reciprocal, bidirectional relationship between these two variables (Bildirici, 2017; Antonakakis et al., 2017).

Extensive research has investigated the relationship between economic growth and environmental quality, with a particular focus on the Environmental Kuznets Curve (EKC) hypothesis (Kuznets, 1955). The EKC framework suggests a non-linear, inverted U-shaped trajectory: initial stages of industrialization typically correlate with rising pollution levels, but once a specific income threshold is reached, further economic progress tends to mitigate environmental degradation, such as CO₂ output (Shafik and Bandyopadhyay, 1992; Vehmas et al., 2007). The EKC hypothesis remains a focal point in contemporary scientific discourse regarding sustainable development. Theoretical models, such as those proposed by Van Alstine and Neumayer (2010), suggest that higher income levels reduce pressure on the environmental sinks. One prominent explanation for this shift is the structural transition from a carbon-intensive manufacturing base toward a service-oriented economy (Jänicke et al., 1997). Consequently, development driven by the tertiary sector is generally considered to be less ecologically damaging than growth rooted in heavy industry.

Empirical evidence regarding the EKC hypothesis remains inconclusive. While several studies provide support for the inverted U-shaped relationship (Kohler, 2013; Shahbaz et al., 2014; Zambrano-Monserrate et al., 2016; Nchofoung and Asongu, 2022; Azam et al., 2025), others fail to find such an association (Govindaraju and Tang, 2013; Baek, 2015; Lacheheb et al., 2015). These disparities are heavily influenced by the methodology used. Broad cross-country panel studies usually confirm the macro-EKC by considering general regional characteristics (Tamazian and Rao, 2010; Azam et al., 2025). However, single-country time-series models that use autoregressive distributed lag (ARDL) or Toda-Yamamoto models often reveal localised linear, neutral or inconsistent paths. In the specific context of Cameroon, research has yielded diverse and mixed insights that challenge uniform, macro-level assumptions. For example, while some single-country ARDL assessments identify a clear inverted U-shaped curve linking economic development to long-term emission stabilization (Njoke et al., 2019), other domestic analyses reveal a linear relationship in which growth consistently increases atmospheric pollution (Nkengfack et al., 2014; Djepang Kouamo and Adamou Hadji, 2021). In this localized debate, Tamba (2017) identified a bidirectional, reciprocal link between CO₂ and growth, and Engo (2018) emphasized the impact of industrial growth on decoupling CO₂ emissions from economic growth in Cameroon. Furthermore, Hossain et al. (2021) identified economic activity as the main driver of rising CO₂ emissions during the late 20th century. This empirical instability is fundamentally tied to Cameroon's idiosyncratic sectoral composition, in which an infrastructure-constrained manufacturing sector, an intensive primary sector and a transport-heavy informal tertiary sector exhibit highly independent emission trajectories (Htike et al., 2022). Disaggregating these sectors is therefore vital in order to ascertain whether Cameroon's ongoing structural transitions are promoting genuine ecological decoupling.

Despite the growing body of literature on this topic, a significant gap remains: existing research treats gross domestic product (GDP) as a monolithic entity. Relying on aggregate GDP data can lead to incomplete or misleading conclusions. Aggregate models mask the vastly different pollution trajectories of individual sectors by smoothing over the structural variations inherent in a developing economy. For example, expansion in a carbon-intensive industrial sector can generate very different environmental outcomes to growth driven by services or agriculture, even if both result in identical aggregate GDP growth. Consequently, failing to isolate these structural shifts can misclassify the true turning point of the EKC and lead to poorly targeted environmental policies.

This study advances existing knowledge by explicitly decomposing Cameroon's GDP into its sectoral components. This granular approach moves beyond the oversimplification that all economic activities impact the environment uniformly (Jänicke et al., 1997). By disentangling the specific ecological footprints of agriculture, industry, and services, this paper provides the empirical precision needed to design effective, sector-specific structural mitigation policies and targeted technological upgrades.

In Cameroon, it is observed that CO₂ emissions have highly increased (48%) since 1971, passing from 0.246 metric tons per capita in 1991 to 0.306 metric tons per capita in 2019. In the same period, there is a low increase (3.3%) of CO₂ emissions in Western and Central Africa. Beside this growth of CO₂, the economic performances of Cameroon have been unstable and negative over the period from 1986 to 1994. However, since the devaluation in 1994, the national economy has found positive economic growth path (passing from 2.063% in 1994 to 3.6% in 2022 - WDI, 2024), with a contribution of a secondary sector of less than 30% on average per year (INS_Comptes Nationaux, 2019).

This study contributes to the existing literature in three distinct ways. First, departing from traditional aggregate models, we re-evaluate the Environmental Kuznets Curve by disaggregating GDP into its primary, secondary, and tertiary components. This approach allows for a precise determination of how various economic sectors specifically drive CO₂ emissions. Second, this research expands the EKC framework by integrating a comprehensive suite of control variables—including trade openness (Lau et al., 2014; Farhani and Ozturk, 2015), energy consumption (Saboori and Sulaiman, 2013; Baek, 2015; Zambrano-Monserrate et al., 2016; Azam et al., 2025), and population density (Shafiei and Salim, 2014; Apergis and Ozturk, 2015)—to ensure a more robust econometric specification. Finally, we address a methodological gap in previous Cameroonian studies (e.g., Nkengfack et al., 2014; Tamba et al., 2014) by incorporating a quadratic (squared) GDP term. By doing so, we are able to empirically identify

the specific income threshold, or 'turning point,' at which CO₂ emissions begin to decouple from economic growth in Cameroon.

The subsequent sections of this paper are structured as follows: Section 3 provides details of the data sources, variable definitions, and the econometric methodology employed. Section 4 provides a comprehensive report and discussion of the empirical findings. Section 5 concludes the study by summarising the results and relevant policy implications.

2. Data and methods

Data for this study was collected from World Development Indicators (CD-ROM, 2024) and INS_Comptes Nationaux (1975–2019) for GDP per sector. It includes annual data on an environmental indicator defined as per capita CO₂ emissions in metric tons, per capita real GDP (total and by sectors) in constant 2000 LCU (local currency), energy use (kg of oil equivalent per capita), trade openness [(imports of goods and services (constant LCU) plus exports of goods and services (constant LCU) divided by GDP (constant LCU)], and population density (people per square km of land area).

The main way in which carbon-intensive industrial production is transmitted is through energy consumption. As clean energy constitutes a very small proportion of Cameroon's industrial energy mix, aggregate energy consumption is a much more accurate indicator of the country's actual carbon footprint. Population density indicates demographic pressure on local ecosystems, while trade openness shows the extent to which Cameroon is integrated into global markets, thus testing the 'pollution haven' hypothesis. Although institutional quality is a vital driver, we excluded it from the econometric estimates because reliable institutional quality datasets, such as the World Bank's Worldwide Governance Indicators (WGI), only begin in 1996. Including them in our estimates would further reduce our already small sample size. Furthermore, including additional macroeconomic regressors in a model with only 41 observations would severely reduce our degrees of freedom, potentially leading to over-parameterised models and multicollinearity. Table 1 shows the summary statistics of each variable used in the analysis.

Table 1: Descriptive statistics of time series

Variables	Variable names (Definition and Units)	Obs*	Mean	Std. Dev.	Min	Max
CO2	carbon dioxide emissions (metric tons per capita)	54	0.2385789	0.1680646	0.0506136	0.6744345
GDPprimca	GDP from primary sector per capita (constant LCU)	41	107520	23283.45	73970.31	149178.7
GDPsecondca	GDP from secondary sector per capita (constant LCU)	41	128736.2	37706.96	55027.1	214874.9
GDPtertca	GDP from tertiary sector per capita (constant LCU)	41	154333.5	29070.53	100518.8	221999.7
gdpcapita	GDP per capita (constant LCU)	56	429881.1	85031.05	306392.6	648525.9
energyuse	energy use (kg of oil equivalent per capita)	44	388.6156	31.23886	317.9248	429.4072
popdensity	population density (people per square kilometer)	55	26.23598	11.35978	11.58112	49.38372
trade_open	Trade openness captured using trade flows divided by GDP. (Exports+imports)/GDP	56	0.3474105	0.0842926	0.224977	0.5249875
gdpcapita2	Gross domestic product (GDP) per capita-squared	56	1.92e+11	7.87e+10	9.39e+10	4.21e+11
GDPprimca2	GDP from primary sector per capita-squared (constant LCU)	41	1.21e+10	5.18e+09	5.47e+09	2.23e+10
GDPsecondca2	GDP from secondary sector per capita-squared (constant LCU)	41	1.80e+10	1.05e+10	3.03e+09	4.62e+10
GDPtertca2	GDP from tertiary sector per capita-squared (constant LCU)	41	2.46e+10	9.13e+09	1.01e+10	4.93e+10

Note: * the number of observations differs because of missing data.

In Table 1, the average value of Carbon dioxide (CO₂) per capita is 0.238, which implies that the average individual in this country contributed about 0.238 metric tons of CO₂ per year. The average per capita Gross Domestic Product (GDP) value for the entire sample is 429 881 FCFA, and 107 520 FCFA, 128 736 FCFA and 154 333 FCFA, respectively in the primary, secondary and tertiary sectors. This implies that on an average, a person living in Cameroon earns about 429 881 FCFA per annum. But this differs according to different sectors. Thus, a person earns annually about 107 520 FCFA in primary, 128 736 FCFA in secondary, and 154 333 FCFA in tertiary

sector. With regards to the value of trade during the period, the entire sample had an average value of 34.7% of trade as a share to the GDP. We also note in table 1 that a person living in Cameroon uses energy for about 388.6 kg of oil equivalent per year. The current population of Cameroon in 2022 is 27,914,536. The density of the population is 26 people. This means that, in Cameroon, on average, 26 people live in each square kilometer of land area.

This study applied the Pesaran et al. (2001) autoregressive distributed lag (ARDL) approach to test the presence of cointegration within the variables and estimate the long-run and short-run coefficients of the variables. Comparing to other approaches, the ARDL approach has several advantages (Engle and Granger, 1987; Jalil and Mahmud, 2009). One of the main advantages of this method is that it allows different integration orders for each series. Furthermore, it can also aid in avoiding problems associated with estimating short-time series data (Haug, 2002; Al-mulali et al., 2016). Moreover, the appropriate modification of the orders of ARDL model is sufficient to correct residual serial correlation and endogeneity (Pesaran and Shin, 1999; Saboori and Sulaiman, 2013). Finally, the estimation is possible even when the explanatory variables are endogenous (Pesaran and Shin, 1999; Pesaran et al., 2001). The ARDL model is suited to handling potential endogeneity between economic growth and carbon emissions without relying on external instrumental variables. Pesaran and Shin (1999) and Pesaran et al. (2001) demonstrated that, once an appropriate lag length has been selected, the dynamic structure of the ARDL model inherently controls for endogeneity. Augmenting the regression with a sufficient number of lagged changes of both the dependent variable and the regressors enables the ARDL dynamic framework to filter out contemporaneous correlation between the regressors and the error term. The Akaike Information Criterion (AIC) was used to select the optimal lag structure for the ARDL model. In this study, the ARDL unrestricted model is used with aggregated GDP (equation 1) and disaggregated GDP on different sources of GDP such as the primary, secondary and tertiary sectors (equation 2).

$$\begin{aligned} \Delta CO2 = & c + \sum_{i=1}^k \alpha_0 \Delta CO2_{t-i} + \sum_{i=0}^k \alpha_1 \Delta gdp capita_{t-i} + \sum_{i=0}^k \alpha_2 \Delta gdp capita 2_{t-i} + \\ & \sum_{i=0}^k \alpha_3 \Delta energy use_{t-i} + \sum_{i=0}^k \alpha_4 \Delta pop density_{t-i} + \sum_{i=0}^k \alpha_5 \Delta trade_open_{t-i} + \\ & \eta_0 CO2_{t-1} + \eta_1 gdp capita_{t-1} + \eta_2 gdp capita 2_{t-1} + \eta_3 energy use_{t-1} + \\ & \eta_4 pop density_{t-1} + \eta_5 trade_open_{t-1} + \varepsilon_t \end{aligned} \quad (1)$$

$$\begin{aligned} \Delta CO2 = & \gamma + \sum_{i=1}^k \delta_0 \Delta CO2_{t-i} + \sum_{i=0}^k \delta_1 \Delta GDP prim ca_{t-i} + \sum_{i=0}^k \delta_2 \Delta GDP second ca_{t-i} + \\ & \sum_{i=0}^k \delta_3 \Delta GDP tert ca_{t-i} + \sum_{i=0}^k \delta_4 \Delta GDP prim ca 2_{t-i} + \sum_{i=0}^k \delta_5 \Delta GDP second ca 2_{t-i} + \\ & \sum_{i=0}^k \delta_6 \Delta GDP tert ca 2_{t-i} + \sum_{i=0}^k \delta_7 \Delta energy use_{t-i} + \sum_{i=0}^k \delta_8 \Delta pop density_{t-i} + \\ & \sum_{i=0}^k \delta_9 \Delta trade_open_{t-i} + \beta_0 CO2_{t-1} + \beta_1 GDP prim ca_{t-1} + \beta_2 GDP second ca_{t-1} + \\ & \beta_3 GDP tert ca_{t-1} + \beta_4 GDP prim ca 2_{t-1} + \beta_5 GDP second ca 2_{t-1} + \beta_6 GDP tert ca 2_{t-1} + \\ & \beta_7 energy use_{t-1} + \beta_8 pop density_{t-1} + \beta_9 trade_open_{t-1} + v_t \end{aligned} \quad (2)$$

$C, \alpha_j, \eta_j, \gamma, \delta_I$ and β_I are the estimated coefficients (with j = from 0 to 5; I = from 0 to 9). ε_t and v_t are error terms, t is year, and k is number of lag. Variables in the level form terms capture the long-run effect while those in first difference (Δ) capture the short-run effects. Given the implications of trade openness, energy use, and population density on carbon emissions (Acheampong, 2018; Haroldo et al., 2019; Zarco-Periñán et al., 2021; Lachehed et al., 2015), the incorporation of these variables in the model will provide more information and also prevent variable omission bias.

The long-run relationship among the variables is verified using the ARDL bounds test where the null hypothesis representing no cointegration is $\eta_0 = \eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 = 0$ in equation (1) and $\beta_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = \beta_9 = 0$ in equation (2); and the alternative hypothesis representing cointegration is $\eta_0 \neq \eta_1 \neq \eta_2 \neq \eta_3 \neq \eta_4 \neq \eta_5 \neq 0$ in equation (1) and $\beta_0 \neq \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq \beta_9 \neq 0$ in equation (2). The calculated F-statistics value is compared with lower critical bound and higher critical bounds from Pesaran et al. (2001). Narayan (2005) suggested alternative critical values which fit better for small sample sizes. For cointegration it is required that the null hypothesis is rejected. The selection of the optimal lag length is analysed through the Schwarz information criteria.

3. Result and Discussion

The empirical analysis started with the stationarity tests of the series (see table 2). In table, we can note that the CO₂, GDPprimca, GDPtertca, gdpcapita, energyuse, popdensity, gdpcapita2, GDPprimca2, and GDPtertca2 variables are individually integrated of order one, I(1); but GDPsecondca, trade_open, and GDPsecondca2 variables are stationary in level, I(0). Thus, an I(0) is a stationary process, and the mean is constant over the series while I(1) is a non-stationary process, and the mean is not constant over series. Therefore, the first differences are used to make an I(1) stationary.

Table 2: Unit root test

Variables	ADF test statistics				k	I(n)
	Model with intercept and trend	Model with intercept	Model without intercept and trend			
Co2	-2.654	-2.586	-1.072	1		I(1)
Δ Co2	-6.529***	-6.576***	-6.621***	1		
GDPprimca	-1.382	-1.121	-0.460	1		I(1)
Δ GDPprimca	-4.434	-4.464***	-4.503***	1		
GDPsecondca	-3.422	-3.258**	-0.361	1		I(0)
GDPtertca	-2.212	-2.220	0.236	1		I(1)
Δ GDPtertca	-3.319*	-3.342**	-3.371***	1		
gdpcapita	-1.770	-1.694	0.327	1		I(1)
Δ gdpcapita	-3.767**	-3.806***	-3.780***	1		
energyuse	-2.154	-0.810	-0.637	1		I(1)
Δ energyuse	-5.527***	-4.915***	-4.861***	1		
popdensity	0.770	0.662	-0.275	3		I(1)
Δ popdensity	-6.158***	0.142	0.529	3		
trade_open	-3.317*	-0.325	1.167	1		I(0)
gdpcapita2	-1.946	-1.886	-0.190	1		I(1)
Δ gdpcapita2	-3.648**	-3.688***	-3.679***	1		
GDPprimca2	-1.632	-1.136	-0.646	1		I(1)
Δ GDPprimca2	-4.681***	-4.735***	-4.774***	1		
GDPsecondca2	-3.526*	-3.267**	-1.203	1		I(0)
GDPtertca2	-2.315	-2.320	-0.198	1		I(1)
Δ GDPtertca2	-3.314*	-3.346**	-3.370***	1		

Note: *, **, *** Indicate statistical significance at 10%, 5% and 1% levels, respectively. k is the lag length. Δ represents 1st difference, I(n) means integrated of order n.

In addition, the unit root test results confirm the absence of I(2). Thus, ARDL model is used given that this approach can be used regardless of whether the data are integrated of order I(0) or I(1). ARDL model results are presented in two parts, one with aggregated GDP (3.1) and another with disaggregated GDP by sector (3.2).

3.1. Relationship between aggregated GDP and Co₂ emissions

Tables 3 and 4 show, respectively, the long and short-run relationships between CO₂ emissions and economic growth, energy use, population density, and trade openness. In order to verify a long-run relationship between these variables (i.e. cointegration), F-statistic of cointegration is estimated. Since the calculated value of F exceeds critical value for I(1) regressors at 10%, 5% and 2.5% of significance (see F-Bounds Test in tables 3 or 4), the null hypothesis is rejected: a cointegration relationship between CO₂ emissions, economic growth, energy use, population density, and trade openness can be justified.

The estimated model also passes the diagnostic tests of serial correlation, heteroskedasticity, normality, and stability test (the results of these tests are reported in the lower part of table 3). Results do not suggest the presence of any serial correlation and heteroskedasticity. They also show that the residuals follow a normal distribution and the coefficients of the aggregated model are stable (see also CUSUM and CUSUMQ techniques from fig. 1 in the appendix which display that the plots of CUSUM and CUSUMSQ statistics are well within the critical bounds, implying that the coefficients in the model are stable).

Table 3: Long run estimates (levels Equation)
Case: restricted Constant and No trend

Dependant variable: <i>CO2t</i>				
Variables	Coefficient ^a	Standard error	T-statistic	
gdpcapita	1.20E-05**	4.70E-06	2.551614	
gdpcapita2	-1.11E-11**	4.78E-12	-2.324121	
energyuse	-0.001921	0.001709	-1.124368	
popdensity	-0.017318*	0.009679	-1.789280	
trade_open	1.455513*	0.856392	1.699588	
c	-2.072372**	1.005566	-2.060901	
EC=CO2-(0.0000*gdpcapita-0.0000*gdpcapita2-0.0019*energyuse 0.0173*popdensity+1.4555*trade_open-2.0724)			-	
F-Bounds test Null Hypothesis: No levels relationship				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	3.834962	10%	2.08	3
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.14
Diagnostic test statistics		Test-stats	p-Value	
Serial correlation		0.677	0.4106	
Normality		4.17	0.1244	
Heteroskedasticity		1.04	0.3084	
Model stability		0.4029	1.3581	
Estimated turning points: 545 454.545 FCFA				

Note ^a : *, **, *** Indicate statistical significance at 10%, 5% and 1% levels, respectively.

Table 4: Short run estimates (ARDL Error Correction Regression)
Case: restricted Constant and No trend, Selected model ARDL(1,1,1,1,0,0)

Dependant variable: D(CO2)				
Variables		Coefficient ^a	Standard error	T-statistic
D(gdpcapita)		9.28E-08	3.90E-06	0.023763
D(gdpcapita2)		1.57E-12	4.03E-12	0.390719
D(energyuse)		0.002583	0.001851	1.395840
CointEq(-1)		-0.829623***	0.146938	-5.646071
R-squares		0.484847	Mean dependent var	0.004527
Adjusted R-squares		0.444177	S.D. dependent var	0.141888
S.E. of regression		0.105783	Akaika info criterion	-1.564466
Sum squared resid		0.425220	Schwarz criterion	-1.398974
Log likelihood		36.85379	Hannan-Quinn criter	-1.503807
Durbin-Watson stat		1.852496	Number of observation	42
F-Bounds test Null Hypothesis: No levels relationship				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	3.834962	10%	2.08	3
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.14

Note ^a : *, **, *** Indicate statistical significance at 10%, 5% and 1% levels, respectively.

The results of long-run estimation show that the linear term of GDP is positive and the non-linear term negative, which proves the existence of the inverted-U relationship between economic growth and CO₂ emissions. This inverted U-shape illustrates a transition in which structural and technical effects (driven by growth in the service sector and gradual efficiency gains) eventually outweigh the resource intensive scale effects of the early stages of development. However, this aggregate decoupling is fragile in structure; rather than reflecting a green technological transition within the primary and secondary industries, Cameroon's direct shift from agriculture to services primarily sustains the downward trend. This result is consistent with various studies that examining such relationship (Shahbaz et al., 2014; Kiviyiro and Arminen, 2014 and Apergis and Ozturk, 2015; Azam et al., 2025).

Contrary to Ohlan (2015), Shahbaz et al. (2015) and Zhu and Peng (2012), the long-run coefficient of CO₂ emissions with population density is negative, indicating that an increase of 1 person per square kilometer of the land area will decrease CO₂ emissions per capita by 0,017 metric tons. This result is not consistent with the expected signs of the study. This can be explained by the fact that the people per square kilometer of land area in Cameroon is very low (in average 26 people per square km). This can also be explained by the increase in the level of development in the long-run. In fact, evidence supports the idea that the scaling between emissions and population depends on the degree of economic development (Rybski et al., 2017; Haroldo et al., 2019).

The coefficient of trade openness is positive and statistically significant, indicating the contribution of this variable to environmental degradation in the long-run. This finding is consistent with that of Al-Mulali et al. (2015) in the case of Kenya. It can be explained by the fact that developing countries increase imports of pollution intensive outputs or confirm the pollution haven hypothesis (i.e. the fact that developed countries may now be importing their pollution-intensive output from the developing world and therefore explain the increasing in local air pollution experienced in most developing countries in recent years (Cole, 2004)).

This study showed that the turning point for Cameroon is 545 455 FCFA. Thus, environmental degradation will increase until annual income per capita reached 545 455 FCFA (known as the turning point) and then environmental improvement will occur. Given that the average annual level of income per capita is 429 881 FCFA, this means that Cameroon has not yet reached his turning point. Therefore, this country is still on the increasing slope of Kuznets environmental curve.

Except error-correction term (ECT), all variables in the short-run model are statistically non-significant. This indicates that aggregated GDP has no contribution to CO₂ emissions in the short-term. However, the ECT is negative and statistically significant at 1%, and thus supports the cointegration of the variables included in the long-run model.

3.2. Contribution of disaggregated GDP in CO₂ emissions

Tables 5 and 6 show respectively the long and short run relationships between CO₂ emissions and disaggregated GDP, energy use, population density and trade openness. The calculated value of F exceeds the critical value for I(1) regressors at 10%, 5%, and 1% of significance (see F-Bounds Test in tables 5 or 6). So, we can support the existence of a cointegration relationship between CO₂ emissions, disaggregated GDP, energy use, population density, and trade openness.

The estimated model also passes the diagnostic tests of serial correlation, heteroskedasticity, normality, and stability test (the results of these tests are reported in the lower part of table 5). Results do not suggest the presence of any serial correlation and heteroskedasticity. They also show that the residuals follow a normal distribution and the coefficients of the disaggregated model are stable (see also CUSUM and CUSUMQ techniques from fig. 2 in appendix which display that the plots of CUSUM and CUSUMSQ statistics are well within the critical bounds, implying that the coefficients in the model are stable)

Table 5: Long run estimates (levels Equation)
Case: restricted Constant and No trend

Dependant variable: <i>CO2t</i>					
Variables		Coefficient ^a	Standard error	T-statistic	
GDPprimca		-0.000114***	2.87E-05	-3.951201	
GDPprimca2		5.52E-10***	1.49E-10	3.699488	
GDPsecondca		-2.33E-05***	6.63E-06	-3.509466	
GDPsecondca2		9.05E-11***	2.52E-11	3.588066	
GDPtertca		6.66E-05***	1.51E-05	4.404493	
GDPtertca2		-2.30E-10***	5.66E-11	-4.073409	
energyuse		-0.000649	0.001140	-0.569142	
popdensity		-0.124427***	0.019314	-6.442372	
trade_open		1.126893**	0.460177	2.448827	
c		0.871751	0.508489	1.714394	
EC=CO2-(-0.0001* GDPprimca +0.0000* GDPprimca2-0.0000* GDPsecondca +0.0000* GDPsecondca2+0.0000* GDPtertca-0.0000* GDPtertca2 -0.0006*energyuse -0.1244*popdensity+1.1269*trade_open+0.8718)					
F-Bounds test Null Hypothesis: No levels relationship					
Test Statistic		Value	Signif.	I(0)	I(1)
F-statistic		8.871291	10%	1.8	2.8
k		9	5%	2.04	2.08
			2.5%	2.24	3.35
			1%	2.5	3.68
Diagnostic test statistics			Test-stats	p-Value	
Serial correlation			2.481	0.1153	

Normality	0.98	0.6141
Heteroskedasticity	37.00	0.4691
Model stability	0.2198	1.3581
Estimated turning points for different sector: 103 636.36 FCFA for primary sector, 116 500 FCFA for secondary sector and 133 200 FCFA for tertiary sector		

Note ^a : *, **, *** Indicate statistical significance at 10%, 5% and 1% levels, respectively.

Table 6 : Short run estimates (ARDL Error Correction Regression)
Case: restricted Constant and No trend, Selected model ARDL(2,2,2,1,1,2,2,2,2,1)

Dependant variable: <i>D(Co2)</i>				
Variables		Coefficient ^a	Standard error	T-statistic
D(CO2(-1))		1.138242***	0.133440	8.529214
D(GDPprimca)		-0.000118***	8.99E-06	-13.17794
D(GDPprimca (-1))		9.77E-05***	9.76E-06	10.01408
D(GDPprimca2)		6.07E-10***	4.27E-11	14.20928
D(GDPprimca2 (-1))		-4.58E-10***	4.52E-11	-10.13045
D(GDPsecondca)		-3.15E-06	3.01E-06	-1.047849
D(GDPsecondca2)		-8.31E-13	9.86E-12	-0.084223
D(GDPtertca)		6.66E-05***	5.60E-06	11.88479
D(GDPtertca (-1)))		-8.05E-05***	9.22E-06	-8.728036
D(GDPtertca2)		-1.92E-10***	1.65E-11	-11.64034
D(GDPtertca2 (-1)))		2.32E-10***	2.89E-11	8.028809
D(energyuse)		0.001353	0.000821	1.648348
D(energyuse (-1)))		0.002760**	0.000885	3.117581
D(popdensity)		3.254788**	1.404253	2.317807
D(popdensity (-1)))		13.94547***	1.826945	7.633217
D(trade_open)		0.634329*	0.324108	1.957152
CointEq (-1)		-2.639062***	0.188906	-13.97027
R-squares		0.965657	Mean dependent var	0.004580
Adjusted R-squares		0.938183	S.D. dependent var	0.151368
S.E. of regression		0.037635	Akaike info criterion	-3.418050
Sum squared resid		0.028327	Schwarz criterion	-2.677898
Log likelihood		80.23392	Hannan-Quinn criter	-3.157111
Durbin-Watson stat		2.561582	Number of observation	37
F-Bounds test Null Hypothesis: No levels relationship				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	8.871291	10%	1.8	2.8
k	9	5%	2.04	2.08
		2.5%	2.24	3.35
		1%	2.5	3.68

Note ^a : *, **, *** Indicate statistical significance at 10%, 5% and 1% levels, respectively.

The results of long-run estimation show that the linear terms of GDP coming from the primary and secondary sectors are negative and the non-linear term positive, which present the U relationship between these sources of economic growth and CO2 emissions. Whereas, the linear term of GDP coming from the tertiary sector is positive and the non-linear term negative, which shows the inverted-U relationship between this source of economic growth and CO2 emissions. The U-shaped curve for the primary and secondary sectors reflects the transition from the oil boom of the 1970s to economic diversification in the post-1980s era. Initially, the dominance of low pollution crude oil extraction, coupled with the slowdown of traditional agriculture and manufacturing induced by Dutch disease, kept carbon emissions low relative to GDP. However, the severe terms-of-trade crisis of the mid-1980s (Chauvin, 2017) and subsequent structural adjustment programmes forced Cameroon to diversify its economic base. This post-crisis revival led to the expansion of carbon-intensive, low-technology manufacturing, such as cement and wood processing, and the commercialisation of primary agro-industries. Ultimately, this locked these sectors into an emission-intensive path as they scaled up. Conversely, the inverted U-shaped relationship in the tertiary sector reflects a typical structural shift towards cleaner economic activities as a country develops. In the early stages of growth, expansion in Cameroon's tertiary sector is dominated by highly carbon-intensive and unregulated informal activities, particularly inefficient transport and retail networks. As the service sector matures and expands, it undergoes an internal qualitative shift towards lower-emission, high-value services such as telecommunications, finance and digital trade.

This allows service-driven GDP to decouple from carbon emissions. Overall, these findings imply that although Cameroon's tertiary sector is successfully transitioning towards environmental sustainability, its primary and secondary sectors are still heavily dependent on resources and hindered by bottlenecks in low-tech industrialisation, which poses a critical challenge to the clean-growth goals of the country's Vision 2035 development agenda.

The density of population and trade openness variables are statistically significant and remain the same signs that in table 3.

Estimated turning points for the different sector are 103 636 FCFA for the primary sector, 116 500 FCFA for the secondary sector and 133 200 FCFA for the tertiary sector. Given that the average annual level of income per capita in primary, secondary and tertiary sectors are respectively 107 520 FCFA, 128 736 FCFA and 154 333 FCFA, this means that Cameroon has yet reached his turning point in different sectors. Therefore, CO₂ emission is yet increasing (decreasing) with annual income per capita in the primary and secondary (tertiary) sectors of Cameroon.

Except energy consumption and GDP comes from the secondary sector, all variables in the short-run model with disaggregated GDP are statistically significant. The negative and statistically significant (at the 1% level) error correction term (CointEq(-1)) confirms a stable long-run cointegrating relationship among the variables included in the long-run model with disaggregated GDP. With a coefficient of -2.64, it indicates an exceptionally rapid speed of adjustment. This implies that system-wide deviations from long-run equilibrium following an economic shock are corrected within the same year. In the short term, the primary and tertiary sectors maintain significant U- and inverted U-shaped relationships with emissions, respectively, reflecting immediate carbon dynamics during economic fluctuations. Conversely, the secondary sector's short-run coefficients are statistically insignificant, demonstrating that industrial emissions in Cameroon do not respond dynamically to short-term output fluctuations. This insignificance highlights deep structural rigidity: Cameroon's industrial base is constrained by low-technology manufacturing lock-ins and infrastructure bottlenecks, preventing the sector from adapting its emissions profile dynamically in response to short-term business cycles.

4. Conclusion

The objective of this paper is not only to examine the contribution of growth to air pollution but also to identify the contribution of each activity sector to environmental degradation. To achieve the objective of this study, the ARDL approach was utilized with data from World Development Indicators (CD-ROM, 2024) and INS_Comptes Nationaux of Cameroon (1975-2019). The results justify a long-run relationship i.e., cointegration among the considered variables in the models with aggregated and disaggregated GDP while the short run relationship is not significant.

In the model with total GDP, results suggest that CO₂ emissions increase as the economy grows (a 1 FCFA increase in GDP per capita corresponds to a 0.000012 metric ton increase in per capita CO₂ emissions), but eventually decrease once the per capita GDP reaches a certain threshold. At this turning point which is 545 455 FCFA in Cameroon, environmental degradation will decrease when the economy grows (a 1 FCFA increase in GDP per capita will lead to a 0.000000000111 metric ton reduction in per capita CO₂ emissions in the long-run). Considering the average annual level of income per capita, we can say that Cameroon has not yet reached his turning point. In this model we also note that no evidence for EKC in the short-run was obtained.

In the model with disaggregated GDP, the results of long-run estimation show the U relationship between CO₂ emissions and GDP come from the primary and the secondary sector. In fact, before the turning point, a 1 FCFA increase in GDP per capita that coming from the primary or the secondary sector, will lead respectively to a 0.000114 and 0.0000233 metric ton reduction in per capita CO₂ emissions. But, after the turning point, a 1 FCFA increase in GDP per capita coming from the primary or the secondary sector, corresponds respectively to a 5.52E-10 and 0.905E-10 metric ton increase in per capita CO₂ emissions. Moreover, we find the inverted-U relationship between CO₂ emissions and GDP that coming from the tertiary sector. In fact, before the turning point, a 1 FCFA increase in GDP per capita come from tertiary sector corresponds to a 6.66E-05 metric ton increase in per capita CO₂ emissions. But, after the turning point, a 1 FCFA increase in GDP per capita that come from tertiary sector will lead to a 2.30E-10 metric ton reduction in per capita CO₂ emissions. Given the average annual level of income per capita in primary, secondary and tertiary sectors, Cameroon has already reached its turning point in different sectors.

Empirical validation of a U-shaped Environmental Kuznets Curve (EKC) in Cameroon's primary and secondary sectors shows that economic growth in these areas is currently increasing carbon emissions. This requires a change in approach, moving from general green mandates to specific sectoral interventions. In the primary sector, where extensive farming and logging are the main drivers of emissions, the government should subsidise environmentally friendly agricultural inputs and climate-smart agricultural inputs to curb land expansion, as well as enforcing stricter penalties on abusive logging practices in order to preserve the country's natural carbon sinks. In the secondary sector, policymakers must incentivise industrial energy efficiency by offering tax breaks to factories that adopt low-carbon manufacturing technologies, and by transitioning heavy industries away from fossil fuels towards Cameroon's hydroelectric and natural gas capacities. Conversely, the inverted U-shaped relationship found in the tertiary sector indicates that service-driven growth is already aligning with environmental sustainability. This momentum should be accelerated by fast-tracking the digitalisation of financial and logistical services to reduce the economy's overall carbon intensity (for example, digitalisation can eliminate empty runs and wasted trips, thereby reducing the need for physical travel. The transport and logistics sector traditionally emits a lot of carbon). Finally, as trade openness increases pollution and population density reduces it, Cameroon must reform its trade and urban policies. This

requires the implementation of strict environmental standards and age limits on imported industrial machinery, as well as investment in low-emission public transport in expanding metropolitan areas such as Douala and Yaoundé, in order to realise the efficiency gains of urban agglomeration.

While this study provides valuable insights into the emissions trajectory of the Cameroonian economy, some limitations must be acknowledged. Firstly, the empirical analysis relies on a small sample size in a country-specific time-series dataset, which limits the generalisability of the findings to other regional contexts. Secondly, due to the small sample size, institutional quality variables were omitted to prevent over-parameterisation. Similarly, as renewable energy currently constitutes a negligible proportion of Cameroon's industrial energy mix, metrics related to renewable energy were excluded in favour of aggregate energy consumption metrics. Future research could address these limitations and examine how the growth-emission nexus evolves as green energy transitions progress.

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Appendix

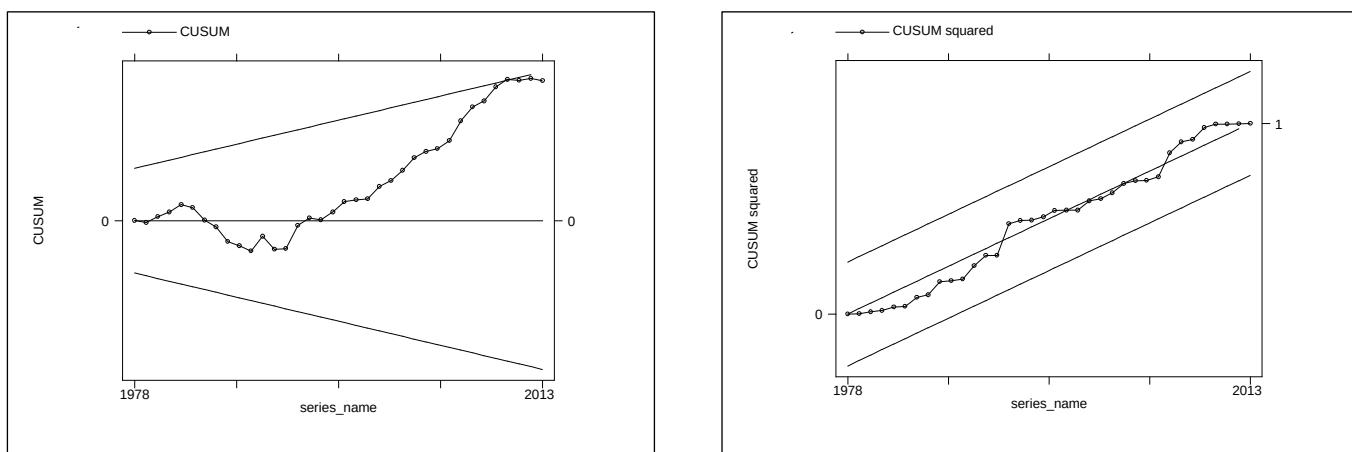


Figure 1: Plot of cumulative sum (and sum of squares) of recursive residual for aggregated model

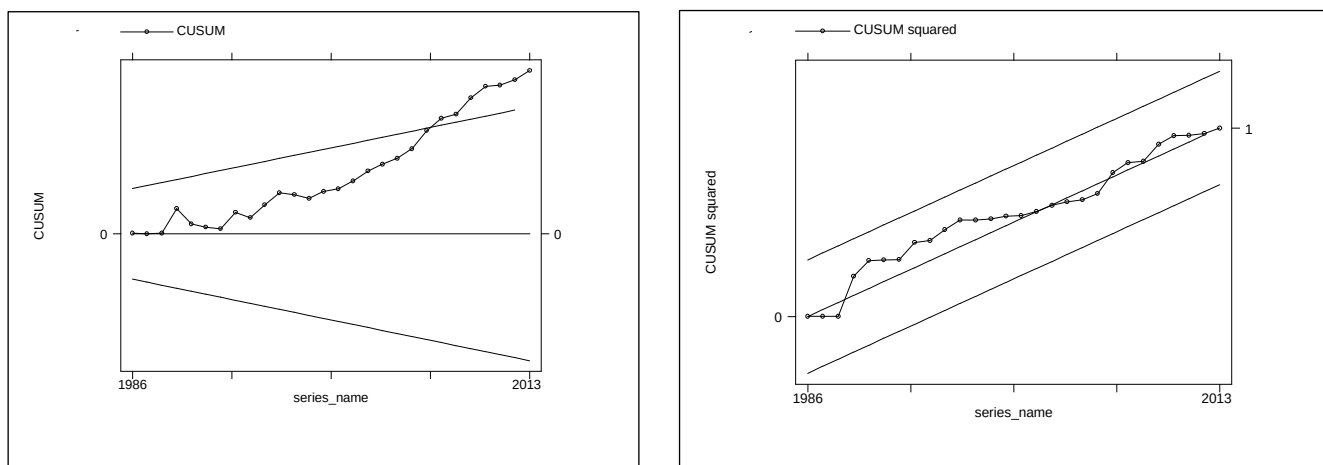


Figure 2: Plot of cumulative sum (and sum of squares) of recursive residual for disaggregated model

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