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Towards environmental degradation mitigation: The role of regulatory quality, technological innovation and government effectiveness in the CEMAC countries

Adnan Khan [a], Agyemang Kwasi Sampene [b,*], Sajjad Ali [b]

[a] University of Waikato Institute, Hangzhou City University, Hangzhou, 310000, China
[b] School of Management, Jiangsu University, Zhenjiang, 212013, China

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ABSTRACT

The study explores the interaction between regulatory quality, economic growth, technological innovation, energy consumption, government spending on research and development, and environmental degradation (EVD) in the Economic and Monetary Community of Central Africa (CEMAC) region. The study applied the econometric approach *CS*-ARDL to estimate the short and long-term interaction between the regressors and the explanatory variable. The study period covers from 1990 to 2020. To summarize the findings of this research, (1) the study discovered a positive relationship between energy consumption, government effectiveness, regulatory quality, and environmental degradation. (2) Economic growth, government spending on research and development, and technological innovation, on the other hand, extensively dissipates EVD in the CEMAC economies. (3) The causality analysis espoused a bidirectional connection between energy consumption, technological innovation, and EVD. (4) Lastly, a unidirectional interplay exists between economic growth, government effectiveness, regulatory quality, and EVD. This study also serves as a reference point for policymakers and governmental institutions to invest in cleaner technologies and increase government research and development spending to mitigate environmental degradation in these areas.

1. Introduction

Macroeconomic factors and environmental degradation (EVD) have been widely debated over two decades. Meanwhile, emerging and developed economies have experienced global warming [1]. The emerging nations of the Economic and Monetary Community of Central Africa (CEMAC) are expanding in their economic growth. Substantial global economic and political adjustments have occurred in the CEMAC nations during the past decade [2]. The CEMAC comprises six economies: Equatoria Guinea, Chad, Central Africa Republic, Cameroon, Gabon, and the Republic of Congo [3]. stipulated that these countries rely heavily on livestock, agriculture, and fossil fuel as their main source of economic expansion. The dependence on these resources has led to an increase in EVD. For example, Equatorial Guinea emitted more than 15 million tonnes of carbon emission, constituting almost 0.03% of worldwide emissions in 2019 [4]. Chad also emitted more than 105 million, equivalent to 0.21 of global pollution. The Central Africa Republic produced more than 46 million tonnes of emission. Cameroon had the highest rate of emission among the CEMAC region with the country emitting

* Corresponding author.
E-mail address: akwasiagyemang91@gmail.com (A.K. Sampene).

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approximately 0.25% (more than 124 million of tonnes) of global pollution. Gabon produced more than 19 million tonnes and the Republic of Congo emitted more than 30 million tonnes of CO_2 [4]. This trend analysis indicates that the level of EVD in these countries are upsurging and it require proper mechanism to neutralize this menace.

From a pragmatic perspective, the CEMAC states represent a particularly intriguing area of inquiry since the economic growth (EGC) and energy consumption (ENC) of these countries have increased exponentially, which has led to a higher level of ecological challenges [5]. Moreover, despite the numerous empirical analyses conducted from different economic blocks [6–8] a literature gap on factors that affect environmental pollution in the CEMAC regions. Therefore, it is critical to fill this literature gap and find a solution to this menace to help the CEMAC economies reach environmental targets stipulated by the United Nations and the Paris agreement [2, 9].

This study is crucial because it provides recommendations for policymakers and other stakeholders in the CEMAC economies on how to promote and carry out ecological stability policies that will lessen EVD in these regions. The current research extended the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) and Environment Kuznets Curve (EKC) by evaluating the effect of economic growth, energy consumption, and technological innovation on EVD in the CEMAC countries. In addition, the study explores the influence of government effectiveness (GE), regulatory quality (RQ), and government spending on research and development (GSRD) on the level of EVD in these regions.

EGC and EVD reduction are mutually reinforcing objectives for national and international low-carbon pathways [10]. Because greenhouse gas emissions contribute to global climate change, ENC and carbon dioxide emissions are a seriously concerned, especially in the CEMAC region [3,11]. Similarly, in most of these CEMAC countries, non-renewable sources of energy are the main mechanism for promoting the manufacturing of goods and services. In addition [12], asserted that CO_2 emissions are the major byproduct of burning coal, contributing to about 42% of global emissions. The CEMAC states need to reduce their reliance on ENC, such as coal, invest in renewable ENC, and strengthen their environmental policies. Extant studies have also proven that over-reliance on non-renewable ENC can lead to the deterioration of the environment [13–15].

Moreover, the effect of TI on EVD has garnered considerable interest from environmental experts [16]. believe that one common trait of emerging economies is the reliance on outdated technology, which causes a rise in global warming and EVD, for which the CEMAC nations have been affected by this trend. It has been discovered by extant studies that the effective use of TI is critical for the expansion of green economies and also serves as a mitigating tool for EVD [17–19]. Therefore, it is essential to evaluate the impact of TI on EVD from the CEMAC economies. Regulatory quality (RQ) and government effectiveness (GE) are critical for conserving environmental quality and the efficient utilization of available natural resources needed for sustainable development [20–22]. The sustainability of natural resources and the conservation of the environment are linked to the RQ and GE [23]. As enunciated by Ref. [5], the assertion that the CEMAC states have to practice political pluralism to promote their governance system indicates a bright spot for these nations. Thus, the shift away from one party state has necessitated financial and economic reforms to strengthen RQ and GE, which should encourage greater environmental conservation policies and programs [5]. Hence, this research evaluates the influence of GE and RQ on EVD in the CEMAC states.

Government spending on research and development (GSRD) is another essential factor influencing environmental stability. The current EVD levels call for governments to provide financial assistance for research into new EVD transition channels and mechanisms to suggest plans and policies to mitigate the negative impact of climate change in the CEMAC countries. Hence previous studies have established that higher investment in GSRD promotes environmental stability [24–27]. Consequently, this study also evaluated the influence of GSRD on EVD in the CEMAC nations. Hence, this research seeks to answer the following questions: (1) Does EGC, TI, and GSRD dispel EVD in the CEMAC region? (2) Does RQ, GE and ENC cause environmental havoc in these emerging economies? (3) What is the causality association among these variables, and what measures should stakeholders take to abate EVD issues in the CEMAC countries?

The present study contributes to extant literary works in four stringent ways: First, by providing an empirical analysis of the effect of TI, ENC, and EGC on EVD, this research expands the environment and energy research in the CEMAC region. Second, this analysis adds to erstwhile studies [2,3,16] by incorporating new variables such as RQ, GE, and GSRD as triggers of EVD for the CEMAC nations from 1990 to 2020. Third, the research provides practical recommendations based on the study's findings. The research recommendations offer practical strategies that governments, policy planners, environmental scientists, and scholars can utilize to help curb and mitigate the high level of ecological destruction in these countries. Lastly, this study used the latest and modern econometric approach to estimate the long-term interplay among the series under consideration. Thus, the empirical approach factored in significant steps, which include; (i) cross-sectional dependency test (CSD), (ii) slope heterogeneity test, (iii) cointegration analysis and cross-sectional autoregressive distributed lag (*C*S-ARDL) estimation approach the long and short run integration between the independent parameter and the explanatory parameter. (iv) The analysis further used the fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) as the robustness evaluation of the *C*S-ARDL approach. (v) The [28] (D-H) causality test was applied to assess the causality connection among the study parameters.

The research is organized as follows in its entirety. Section 2 of this study contains a review of recent literary works. The theoretical context, data, and econometric strategy used in this study are described in Section 3. The empirical findings and discussion are covered in Section 4 of this study. The summary in Section 5 summarizes the study's findings as well as its theoretical and applied implications.

2. Literature review

2.1. Theoretical background

When evaluating the parameters affecting EVD, it is essential to examine the association between EGC and pollution. Hence the EKC hypothesis suggested by Ref. [29] describes the nonlinear linkage between EGC and ECD. The EKC theory asserts that growth may cause higher emissions at lower income levers and lesser pollution at higher income levels [30]. This situation can lead to a U-shaped association between income levels and EVD. Most studies have evaluated or validated whether EVD increases or declines in economies with upsurging EGC within the EKC hypothesis [23,31]. The concurrent deployment of the EKC theory in several environmental research underlines the importance of this concept in the formation of national green policies [32–34]. Thus, the EKC model contends that because a higher level of EGC results in the utilization of more consumption of raw materials, energy, and natural resources, they significantly contribute to ecological devastation. Contrastingly, wealth expansion surpassing a benchmark or threshold contributes to the decline in EVD as individuals and organizations become more conscious of the issues with EVD and hence establish effective pollution laws [1,23,35]. Several environmental studies have investigated the ECK model. For instance Ref. [36], for BRICS economies [37], for 54 Africa Union economies [38], for Gulf Corporation Council (GCC). In addition to the ECK theory, the research further incorporated the STIRPAT model to examine the influence of technological innovation, regulatory quality, and GSRD on EVD in the CEMAC economies. The next section of this chapter discusses empirical studies that evaluated the association between variables such as EGC, ENU, and EVD. In addition, the connection between TI-EVD, RQ-EVD, GE-EVD, and GSRD-EVD has been discussed. Some empirical studies that have evaluated the association between EGC-ENC-EVD have been summarized in Table 1.

2.2. Economic growth, energy consumption, and environmental degradation nexus

The examination of the ENC-EGC-EVD dilemma has been ramified over the last decades, dividing environmental research on this topic into two phases. The first stream of research evaluated the connection between EVD and EGC through the EKC and the STIRPAT model established by Refs. [11,29,52,53]. The underlying assumption of these theories is that while an economy first flourishes at the

Table 1
Summary of related studies.

Authors	Time Frame	Indicators Used	Economy	Findings
[39]	1990–2013	EVD, EGC, ENC	MINT	EGC → EVD (+) ENC ← EVD (−)
[40]	1971–2014	EVD and EGC	Pakistan	EGC → EVD (+)
[41]	1984–2016	EVD and EGC	Emerging Economies	EGC → EVD (+)
[42]	1995–2016	EVD, EGC, ENC	ASEAN	EGC → EVD (+) ENC → EVD (+)
[43]	1971–2017	EVD, EGC and ENC	MINT	EGC → EVD (+) ENC ← EVD (+)
[44]	1990–2016	EVD, EGC, and ENC	South Asian	EGC → EVD (+) ENC → EVD (+)
[45]	1990–2015	EVD, EGC, and ENC,	G7 economies	EGC → EVD (+) ENC → EVD (+)
[46]	1971–2016	EVD and ENC	China and Brazil	ENC → EVD (−)
[2]		EVD, EGC and RQ	CEMAC	EGC → EVD (+) RQ ← EVD (+)
[15]	1990–2018	EVD, EGC, and ENC	BRICS-T	EGC → EVD (+) ENC ← EVD (−)
[47]	1983–2017	EVD, EGC, and ENC	Brazil	EGC → EVD (+) ENC ← EVD (−)
[3]	1980–2018	EVD and EGC	CEMAC	EGC → EVD (+)
[48]	1980–2017	EVD, EGC, ENC	USA	EGC → EVD (+) ENC ← EVD (−)
[49]	1990–2017	EVD, ENC and TI	China	TI ← EVD ENC ← EVD (−)
[16]	1960–2014	EVD, EGC, and ENC	CEMAC	EGC → EVD (+) ENC ← EVD (−)
[19]	1990–2020	EVD, EGC, ENC	MINT	EGC → EVD (+) ENC ← EVD (−)
[50]	1960–2020	EVD, EGC, and ENC	South Africa	EGC → EVD (+) ENC → EVD (+)
[51]	1984–2017	EVD, EGC, and ENC,	G11 economies	EGC → EVD (+) ENC → EVD (+)

Note: EVD = Environmental degradation (CO_2 emission and ecological footprint) ENC= (Renewable and Non-renewable energy sources), EGC = Economic growth (GDP),TI= Technological Innovation, MINT = Mexico, Indonesia, Nigeria and Turkey, → Positive association, ← negative association.

expense of EVD, this trade-off progressively lessens as advanced stages of industrial growth support environmental progress. Several studies in recent times have applied the STIRPAT approach and EKC in evaluating the ecological impact of technology, population, affluence, and other variables on environmental degradation from different jurisdictions [54–56]. The second stream of studies also has documented that higher environmental pollution results from emissions from ENC, such as coal, natural gas, and fossil fuel, for economic development [23,57]. ENC is anticipated to cause an upsurge in the activities of manufacturing industries which will accelerate EGC. Hence the increased demand for ENC could influence EVD. This is because burning coal releases greenhouse gas which is deemed to be damaging to the sustainability of the environment [50,58,59].

2.3. Technological innovation and environmental degradation nexus

The existing studies on the TI-EVD nexus have resulted in conflicting outcomes. While some authors argue that the effective use of TI reduces EVD, other schools of thought have established that TI has a detrimental influence on EVD. For instance Ref. [18], explored the connection between TI-EVD by applying a panel dataset from 1980 to 2018. The empirical findings from their research proved that environmental sustainability could be achieved by using TI for economic development in Malaysia. Likewise [60], also established in their research that the higher level of environmental destruction could be corrected with the advancement in TI in the BRICS economies. In addition [61], explored the interplay between TI-EVD and reported that TI improves ecological stability. Similarly, the study by Ref. [62] for European Union economies [19], for Mexico, Indonesia, Nigeria, and Turkey (MINT) [63], for South Africa have empirically proposed that the progression of TI has helped improve ecological stability in these regions. Nevertheless, the empirical findings from Ref. [64] for BRICS [17] for Asia Pacific Economic Cooperation (APEC) [49] found that TI impedes ecological stability. In conclusion, given that the literature has not yet come to a resolution, it may be analyzed the effects of TI on EVD have yielded contradictory outcomes.

2.4. Regulatory quality and environmental degradation nexus

A theory propounded by Ref. [65] pointed out that EVD may be associated with the effectiveness and efficiency of regulatory and institutions linked to legal mechanisms for supervising, evaluating, and enacting compliance requirements [66]. argued that economies that develop precise regulations and guidelines regarding permit issuance, taxation, and charges on fees could expect enterprises to follow the regulatory framework regarding production and firm waste management systems. Furthermore [66], reported that it is theoretically proven that RQ increases EXP, which is likely to impact EVD [67]. confirmed in their research that RQ and policies help improve environmental degradation. In Saudi Arabia [68], reported a significant and adverse impact of RQ on EVD. Their study recommends that it is essential to improve RQ and ensure that enterprises follow these regulations to help eradicate environmental degradation [22]. reported that RQ caused an upsurge in renewable and non-renewable energy use among the South Asia economies.

2.5. Government effectiveness and environmental degradation nexus

Government effectiveness (GE) is very vital in controlling environmental degradation. Thus GE may include bureaucratic system and inefficiencies, the perception of poor governance, mismanagement of funds within the public sector, and specifically ineffective government environmental control mechanism [22,66]. Few studies have examined the nexus between GE and EVD, especially among the CEMAC economies. However, some studies have reported on the relationship among these variables. For instance Ref. [69], examined the connection between GE and EVD among emerging and developing economies. Their outcome found that GE modifies the relationship between economic growth and environmental degradation [70]. found evidence from the Sub-Saharan countries on the impact of GE on EVD. Their outcome indicated that GE has a negative relationship with environmental degradation. This implies that GE can help dissipate EVD in the BRICS countries [71]. believes that GE supports environmentally friendly initiatives, which impact EVD.

2.6. Government spending on research and development and environmental degradation nexus

Recent literature has found conflicting results on GSRD-EVD [26]. analyzed the impact of GSRD on EVD in the G7 nations with panel data from 1870 to 2014. Their study's outcome indicated that GSRD affects the level of EVD in both positive and negative ways. Thus, GSRD affected EVD through a simultaneous effect on ENC and EGC [72]. also examined the impact of GSRD on EVD using panel data from 1990 to 2013, with the primary focus on justifying GSRD in the context of mitigating EVD. Their findings proved that GSRD contributes to the reduction of EVD. Using panel data from 1990 to 2016 [73], analyzed the nexus between GSRD among the Mediterranean economies. According to their research outcome, GSRD has an adverse and unidirectional impact on EVD. Among the OECD economies [24], findings point out a negative and long-run association between GSRD and EVD. Their research further indicated that an increase in the investment in GSRD would influence a reduction in EVD in the OECD countries. Contrary to this outcome, studies by Ref. [74] found that GSRD increases EVD.

3. Methodology

3.1. Variable definition and unit of measurement

Environmental Degradation (EVD): The explanatory parameter in this study is EVD, which is approximated by the CO_2 emissions of the countries within the study period (1990–2020). The study measures CO_2 in kilo tones, which has been used in several studies [75,76].

Economic growth (EGC): was assessed with the annual economic performance of the CEMAC economies based on the gross domestic product (GDP). Several studies have proven the increase in EGC to positively connect with a higher level of EVD [63,77,78]. Hence in this research, we expect a positive nexus between EGC-EVD.

Energy Consumption (ENC): The estimation of ENC was based on the use of non-renewable energy in the countries under investigation in this research. Thus, ENC was measured with a kilogram of oil equivalent per capita assessed in these studies [7,79,80]. As a result, this study posits a positive association between ENC-EVD.

Technological Innovation (TI): [81] argues that countries can reach carbon neutrality if they invest in technology and innovation. This research focuses on the number of patent applications authorized in a particular country as a measure for TI. Since extant studies have proved that TI can be harnessed to improve environmental sustainability [47,82], this study anticipates an inverse interplay between TI-EVD.

Regulation quality (RQ): This study measures RQ as the government's capability and capacity to initiate policies, plans, and effective regulations that promote and enhance the private sector to develop and contribute to society's advancement. We expect that if there is an effective RQ in the selected countries, it can reduce EVD. Studies by Ref. [83] employed this variable in their analysis.

Government Effectiveness (GE): estimates a country's public services quality, the degree of government independence from a civil group or political pressures, the formulation and implementation of quality plans and policies, and the government's total commitment to such policies to develop the country. Adding such an essential variable in our study is because we assume that an effective government will have a higher responsibility toward carbon neutrality.

Government spending on research and development (GSRD): is vital in the fight against climate change. In this research, GSRD is measured as a total expenditure (current and capital) on research and development carried out by enterprises, research organizations, government research groups, and various universities in a particular country at a point in time [24]. This variable is measured in research and development by %$US (constant USD 2010).

3.2. Data source

The data used to measure EVD, ENC, EGC, and GSRD was collected from World Development Indicator [84], while the dataset for TI was retrieved from Ref. [85]. The data for RQ and GE were obtained from Worldwide Governance Indicator [86]. Table 2 captures the description and unit of measurement for all the study parameters. The analysis of this study was utilized with the social science statistical tool (EVIEWS).

3.3. Econometric estimation approach

The empirical and theoretical basis for choosing the explanatory parameters of this research can be aligned with the theoretical foundation, which includes the STIRPAT [52]. For the STIRPAT model, Stochastic Impacts, I denote the environmental Impacts, P indicates population, A shows a country's affluence, and T depicts environmental technology. Based on this notion, this study incorporated EGC, ENU, TI, RQ, GE, and GSRD to evaluate their impact on EVD. Similar research analyzing these variables and their effect on EVD through the STIRPAT theory includes [17,54,87]. Hence the STIPAT is mathematically expressed in equation (1) as:

$$I_{it} = \alpha P_{it}^{b} \times A_{it}^{c} \times T_{it}^{d} \times \mu_{it} \tag{1}$$

Such that I represent EVD, which is influenced by population (P), affluence (A), and technology (T). The elasticity of the model is indicated with the terms b, c *and* d. The error term is identified by μ, and i symbolize the individual countries under investigation in this

Table 2
Synopsis of the variable description.

Variable	Symbols	Description	Source
Environmental Degradation	EVD	CO_2 emissions in kilo ton (kt)	WDI
Energy Consumption	ENC	Energy Usage (kg of oil equivalent per capita	WDI
Economic Growth	EGC	Per Capita (constant USD $2010)	WDI
Technological Innovation	TI	No. Of patent applications authorized by both resident and non-resident	OECD
Regulatory Quality	RQ	Estimates Government effective regulations	WGI
Government Effectiveness	GE	Estimates on public services quality	WGI
Government spending on research and development	GSRD	R&D measured by %$US (constant $2010)	WDI

Note: WDI: World Development Indicators, WGI: World Governance Indicators, OECD: Organization for Economic Cooperation and Development EGC-Economic Growth, ENC-energy consumption, RQ-Regulatory quality), GE-Government effectiveness, and GSRD-Government spending on research and development.

research and signifies the period of the study. Based on the STIRPAT model and extant studies [17,54,87], the study incorporated the parameter and proposed equation (2):

$$InEVD_{it} = \alpha_i + bInEGC_{it} + cInENC_{it} + dInTI_{it} + eInRQ_{it} + fInGE_{it} + gInGSRD_{it} + \varepsilon_{it} \tag{2}$$

such that InEVD (Environmental degradation), InEGC (Economic Growth), In InENC (energy consumption), InRQ (Regulatory Quality), InGE (Government effectiveness), and InGSRD (Government spending on research and development) are represented in their natural logarithm forms. The elasticity of the model is indicated with the terms $a - g$. The error term is identified by μ, and i symbolize the individual countries under investigation in this research. t signifies the period of the study (1990–2020).

3.3.1. Cross-sectional dependence test

To ascertain any cross-sectional dependency (CSD) issues in the data parameters, the study applied three estimation approaches: Breusch-Pagan LM, Pesaran scaled LM, and Pesaran CD, as suggested by Ref. [88]. Previous studies have established that the presence of CSD in the data may result in erroneous conclusions [89,90]. Equation (3) indicates the mathematical formulae for the CSD test.

$$CSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\delta_{ij}^{t}\right) \tag{3}$$

where T symbolizes the cross-sections between the measurements, δ_{ij}^{t} stands for correlation residuals of the calculated model, and N represents the period.

3.3.2. Slope homogeneity test

After assessing the CSD [91], added that the panel data should be devoid of heterogeneity issues since it might lead to an inaccurate outcome. Hence to account for the homogeneity, the study employed a methodology espoused by Ref. [92] to evaluate the slope homogeneity across the panel data sets, which is provided in equations (4) and (5):

$$\widetilde{\Delta}_{SHT=}N^{)}(2K)^{\frac{-1}{2}}\left(\frac{1}{N}\widetilde{S} - K\right)\Big) \tag{4}$$

$$\widetilde{\Delta}_{ASHT=}N_{)}\left(\left(\frac{2k(T-k-1}{T+1}\right)^{\frac{-1}{2}}\right)\left(\frac{1}{N}\widetilde{S} - K\right)\Big) \tag{5}$$

where $\widetilde{\Delta}_{SHT}$ identifies the delta of the SH and $\widetilde{\Delta}$ASHT stands for the adjusted SH.

3.3.3. Unit root test

The second-generational panel unit root test was also used to determine the degree of stationarity among the series. The investigation used the Cross-sectional Augmented Dickey-Fuller (CADF) and the Cross-sectional I'm Pesaran and Shin models (CIPS). These two-panel data stationary tests (CADF and CIPS) have given more precise estimations than the first-generation unit root test in previous literary works [1,93]. The mathematical formulae for these tests are specified in equations (6) and (7)

$$CADF = \Delta x_{it} = \alpha_{it} + \beta_{it-1} + \delta_l T + \sum_{j=1}^{N}\gamma_{ij}\Delta x_{it-j} + \mu_{it} \tag{6}$$

where Δ demonstrates disparities between the variables, x_{it} implies parameters analyzed in the study, and the error term of the model is indicated with μ.

$$CIPS = \frac{1}{N}\sum_{i=1}^{N}\varphi_i\,(N,T) \tag{7}$$

where T depicts the cross-sections among the parameters and N shows the period.

3.3.4. Cointegration approach

In panel data analysis, it is imperative to evaluate the existence of cointegration among the parameters. As a result, the study employed the Johanson-Fisher [94,95] cointegration approaches to estimate the presence of long-term association among the series. The Johansen cointegration test provided two categories: Max-Eigen and Trace. The specification of the null hypothesis is the basic statistical distinction between this cointegration assessment. The Johanson-Fisher cointegration analysis has the advantage of offering alternate cointegrating among panel datasets. In addition to the Johansen Cointegration approach, the study used the [96] estimation technique. Prior studies have demonstrated that this technique resolves CSD issues and produces accurate outcomes for estimating long-term interaction among panel series [56,97]. The mathematical representation for the four tests of this [96] cointegration analysis is presented in equations 8-11a, 11b:

$$G_\tau = \frac{1}{N}\sum_{i=1}^{N}\frac{\eta_i}{S.E(\widehat{\eta}_i} \tag{8}$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\eta_i}{1-\sum_{j=1}^{k}\widehat{\eta_{ij}}} \tag{9}$$

$$P_\tau = \frac{\widehat{\eta}_i}{S.E(\eta_i} \tag{10}$$

$$P_a = T\eta_i \tag{11a}$$

such that *Pt* and *Pa* represent the panel statistics and *Gt* and *Ga* identify the group means statistics. The speed of movement from the long-term co-efficient is defined with η_i.

3.3.5. Estimation of long-run elasticity

After establishing the long-term cointegration among the study's variables, the analysis employed the *C*S-ARDL technique to assess the long- and short-term association among the study variables. Erstwhile studies have demonstrated that this estimation method produces a dependable, accurate, and robust outcome in panel data analysis [98]. In addition, the *C*S-ARDL overcomes the challenges and issues of panel data, such as CSD, multicollinearity, and dynamic panel disparities [51,60,90]. The equation for this procedure is as follows:

$$\Delta EVD_{i,t} = \delta_i + \sum_{j=1}^{m}\delta_{it}EVD_{i,t-j} + \sum_{j=0}^{m}\delta_{it}\,X_{i,t-j} + \sum_{j=0}^{1}\delta_{it}\,\overline{Z}_{i,t-j} + \mu_{it} \tag{11b}$$

where $\overline{Z}_t = (\Delta EVD_{i,t}, \overline{X}_t)^{'}$ shows the CSD averages and X_{it} denotes regressors in the research model (EGC, ENU, TI, RQ, GE, and GSRD).

3.3.6. Robustness analysis

The study applied the fully-modified ordinary least square FMOLS and DOLS to evaluate the robustness of the *C*S-ARDL approach [99]. The fundamental reason for selecting this econometric approach is that the FMOLS factor in the issues of slope heterogeneity across the panel data section. Moreover, this technique produces a precise and accurate outcome, as indicated by previous studies [58, 100,101]. Additionally, these methods aid in eradicating serial correlation, heteroscedasticity, and endogeneity [37]. To evaluate the robustness of the FMOLS, we employed the dynamic ordinary least square (DOLS) suggested by Ref. [102]. Equations (12) and (13) provide the mathematical expressions for the FMOLS and DOLS models, respectively.

$$FMOLS_{ESTIMATOR} = N^{-1/2}\sum_{i=1}^{N} t\beta_{FMOLS,n} \tag{12}$$

$$DOLS_{ESTIMATOR} = N^{-1/2}\sum_{i=1}^{N} t\beta_{DOLS,n} \tag{13}$$

3.3.7. Causality analysis

The *C*S-ARDL, FMOLS, and DOLS provide information explaining the long-run dynamics connection of the parameter; however, these approaches cannot disclose information on the causality between the series. Hence to verify the causality between EVD, EGC, ENC, TI, RQ, GE, and GSRD, the Dumitrescu and Hurlin (D-H) test was selected to evaluate the causality test [28]. Equation (14) analytically illustrates the D-H non-causality assessment:

Table 3
Descriptive statistics, correlation matrix, and VIF.

Variables	Mean	Std.Dev	Maximum	Maximum	VIF	Correlation
InEVD	6.010	0.867	7.748	5.267	2.364	
InEGC	5.186	0.515	6.778	4.477	3.055	0.583***
InENC	7.714	0.856	5.413	1.880	2.380	0.198***
InGE	3.956	0.335	4.466	2.467	1.457	0.441***
InRQ	3.815	0.494	4.395	0.218	1.035	−0.202***
InTI	8.958	0.503	14.147	4.927	2.032	0.373***
InGSRD	3.138	0.397	9.249	1.342	2.859	0.698***

Note: *** indicates a 1% significance level. EVD-Environmental degradation- EGC-Economic Growth, ENC-energy consumption, RQ-Regulatory quality), GE-Government effectiveness, and GSRD-Government spending on research and development.

$$Y_{it} = \alpha_i + \sum_{m=1}^{M} \psi_i^m, Y_{i(m-t)} + \sum_{m=1}^{M} \lambda_i^m, Z_{i(m-t)} \tag{14}$$

where ψ_i^m displays the model's autoregressive properties with m specifying the lag's duration.

4. Results and discussion

4.1. Descriptive statistics

The descriptive statistics and correlation matrix for the series are presented in Table 3. The mean, standard deviation, and minimum and maximum statistics have been provided for all the series. The correlation matrix shows a positive correlation between InENC, InEGC, InTI, and InGSRD. On the other hand, InRQ has an inverse association with EVD. Correlations can be used to draw certain conclusions, but not enough. More econometric analyses are performed as a result. In addition, the multicollinearity of the variables is evaluated using the variance inflation factor (VIF) approach. According to the results of the VIF test, all statistical values were below the cutoff point of 10 suggested by Refs. [103,104], demonstrating the falsity of the multicollinearity issue with the study model.

4.2. Cross-sectional dependence test and slope homogeneity outcome

The outcome of all the CSD and tests of slope homogeneity are summarized in Table 4. The study's outcome unveiled that at a 1% statistical significance level, all the test statistics reject the null hypothesis of cross-sectional independence to affirm CSD among the research variables. Thus, the result proved that proof that any changes to one economy within the panel would also affect the other countries in the CEMAC block. In addition, in Table 4, $\widetilde{\Delta}$SHT and adjusted $\widetilde{\Delta}$SHT indicates the statistical test for slope homogeneity and the biased adjusted components. The outcome of the SHT analysis provides us with enough and sufficient evidence for the prevalence of economic interdependence in the study proposed model.

4.3. Unit root test outcome

Table 5 displays the results of the second generational panel unit root test- CIPS and CADF for examining the stationarity of the series. The outcome indicated that all the study parameters (InEVD, InEGC, InENC, InTI, InRQ, InGE, and InGSRD) were non-stationary; nevertheless, after the first difference test, all the series became stationary I (1). The establishment of stationarity among the series denotes a possibility of long-term connection among the study variables.

4.4. Panel cointegration test outcome

The result for the two cointegration tests is displayed in Table 6. First, the results of [94]- Johansen's cointegration test indicated that both Max-Eigen and Trace tests confirm the long-run equilibrium link between the series. Moreover, the [95] results confirm that environmental deterioration in the CEMAC nations has long-term interaction with InEVD, InEGC, InENC, InTI, InRQ, InGE, and InGSRD. The outcome of the [96] cointegration test revealed all the parameters evaluated in this study were cointegrated. Hence the study can estimate the short and long-term interaction among the study parameters.

4.5. Short and long-run estimation outcome

The long and short-run estimates for both the *C*S-ARDL are presented in Table 7 and Fig. 1. The research applied FMOLS and DOLS as the robustness test for the *C*S-ARDL, and the results are shown in Table 8.

As proposed in this research, the results of *C*S-ARDL proved that economic growth has an inverse and significant connection with

Table 4
Outcome of CSD test and Test of slope homogeneity.

Series	Bias-Corrected Scaled LM	Pesaran scaled LM	Breusch-Pagan LM
InEVD	194.703***	41.300***	7.1472***
InEGC	172.964***	36.439***	10.071***
InENC	53.372***	9.698***	6.317***
InGE	116.433***	23.799***	9.936***
InRQ	72.991***	14.085***	2.228***
InTI	79.434***	15.525***	5.573***
InGSRD	101.034***	20.355***	9.211***
Test of slope homogeneity			
*Delta tilde*Δ	14.023***		
*Delta tilde adjusted*Δ	14.538***		

Note: *** indicates a 1% significance level. EVD-Environmental degradation- EGC-Economic Growth, ENC-energy consumption, RQ-Regulatory quality), GE-Government effectiveness, and GSRD-Government spending on research and development.

Table 5
Outcome of panel unit root test.

Variables	CADF		CIPS		Decision
	Level	First difference	Level	First difference	
InEVD	1.0628	−9.615***	−1.181	−8.274***	I (1)
InEGC	2.0490	−7.852***	1.691	−4.338***	I (1)
InENC	0.2533	−5.972***	1.164	−12.107***	I (1)
InGE	0.1282	−9.077***	−2.169	−13.052***	I (1)
InRQ	0.9041	−8.625****	−0.740	−11.342***	I (1)
InTI	2.1021	−5.309***	0.229	−8.495***	I (1)
InGSRD	0.9261	−6.691***	−0.826	−7.998***	I (1)

Note: *** indicates a 1% significance level. EVD-Environmental degradation- EGC-Economic Growth, ENC-energy consumption, RQ-Regulatory quality), GE-Government effectiveness, and GSRD-Government spending on research and development.

Table 6
Outcome of panel cointegration test.

Cointegration Construct	Fishers Stats* (Trace Test)	Fisher Stat* (Max-Eigen Test)		
Johansen Cointegration Test				
None	674.2***	175.7***		
At most 1	275.0***	173.5***		
At most 2	212.4***	103.7***		
At most 3	130.1***	57.69***		
At most 4	85.71***	39.15***		
At most 5	55.01***	36.83***		
At most 6	28.90	25.69		
At most 7	18.20	17.10		
Kao, (1999) Cointegration Test		[96]		
	t − Statistics	Test Stats	Z-value	*P*-value
ADF- test	−5.087***	*Gt*	8.314***	0.000
		Ga	1.026	0.673
		Pt	6.074***	0.000
		Pa	0.973	0.885

Note: Note: *** indicates a 1% significance level.

Table 7
Outcome of Short and long-run elasticities (*C*S-ARDL).

Series	Coefficient	Std. Error	T-value	Prob.
Long-term elasticity				
InEGC	−0.572***	0.121	−6.390	0.000
InENC	0.754***	0.017	8.482	0.000
InGE	0.327***	0.182	4.893	0.000
InRQ	0.215***	0.109	3.535	0.001
InTI	−0.184***	0.016	−4.835	0.002
InGSRD	−0.452***	0.084	−7.951	0.000
Short-term elasticity				
InEGC	−0.690***	0.027	−9.367	0.000
InENC	0.436***	0.194	6.748	0.000
InGE	0.830***	0.384	9.732	0.000
InRQ	0.270**	0.063	5.736	0.001
InTI	−0.504***	0.075	−7.316	0.000
InGSRD	−0.721***	0.320	−9.002	0.000
ECT (−1)	−0.844***		−8.634	
R2	0.98			
Adj R2	0.96			

Note: *** indicates a 1% significance level. EVD-Environmental degradation- EGC-Economic Growth, ENC-energy consumption, RQ-Regulatory quality), GE-Government effectiveness, and GSRD-Government spending on research and development.

EVD in the CEMAC states. The implication is that ecological stability in this region is being affected significantly due to economic growth. Surprisingly, this study outcome shows that a 1% upsurge in EGC neutralizes EVD by 0.572% in the long-term and 0.690% in the short-run. This outcome supports the STIRPAT and EKC assumption that when an economy expands, EVD rises. Nevertheless, with advancements in urbanization and modernization, ecological sustainability increases [52,105,106]. This outcome is consistent with previous studies that asserted that economic growth promotes ecological stability [2,43,48,106]. The results have consequences for the decision-makers who must ensure continued economic growth, which will likely lessen environmental pollution by implementing

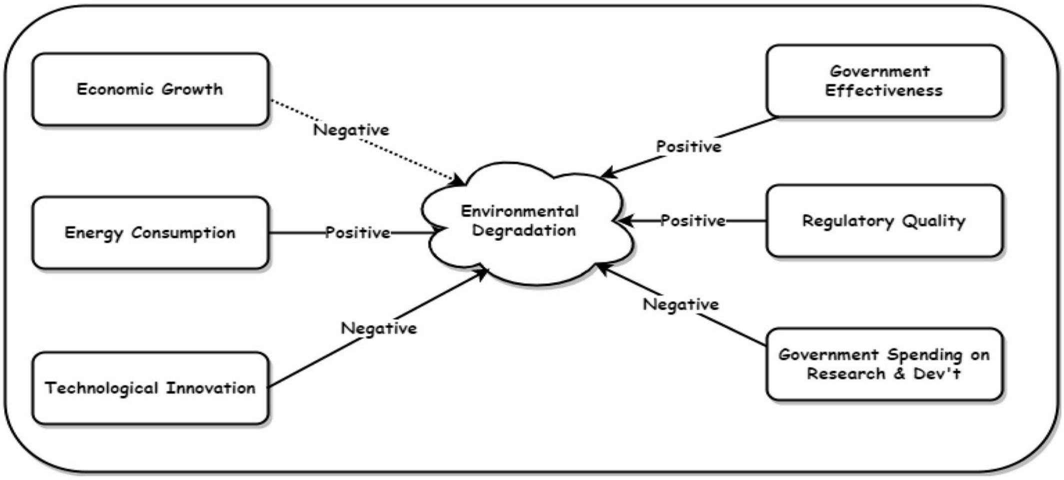

Fig. 1. Graphical representation of empirical results.

Table 8
Outcome of the robustness check (FMOLS and DOLS).

Variables	Coefficient	Std. Error	t-Statistic	Prob.
FMOLS estimates				
InEGC	−0.428***	0.012	−10.802	0.001
InENC	0.757***	0.109	6.933	0.003
InGE	0.089***	0.039	12.284	0.000
InRQ	0.025***	0.020	8.293	0.001
InTI	−0.502***	0.011	−9.060	0.000
InGSRD	−0.151***	0.038	−7.641	0.001
R-squared	0.931			
Adjusted R-squared	0.930			
SE of regression	0.877			
Long-run variance	0.936			
F-statistic	110.875			
Prob (F-statistic)	0.000***			
DOLS estimates				
InEGC	−0.619***	0.124	−9.796	0.000
InENC	0.794***	0.109	7.283	0.000
InGE	0.063***	0.040	8.052	0.001
InRQ	0.022***	0.021	10.338	0.000
InTI	−0.394***	0.011	−9.840	0.002
InGSRD	−0.128***	0.037	−3.343	0.011
R-squared	0.824			
Adjusted R-squared	0.878			
SE of regression	0.856			
Long-run variance	8.256			
F-statistic	73.519			
Prob (F-statistic)	0.000***			

Note: *** indicates a 1% significance level. EVD-Environmental degradation- EGC-Economic Growth, ENC-energy consumption, RQ-Regulatory quality), GE-Government effectiveness, and GSRD-Government spending on research and development.

various safety and quality control measures.

As projected in this study, the influence of ENC on EVD in the CEMAC economies is positive and significant in the long term. Thus, the outcome indicates that a 1% rise in ENU will cause an increase in EVD by 0.754% in the long run and 0.436% in the short-term. These results can be attributed to the assumption that most CEMAC nations rely on non-renewable energy sources, including oil, fossil, and natural gas, for economic expansion. Supporting existing studies [48,77,107,108] established in their papers that ENC in the form of non-renewable sources causes a major threat to ecological sustainability and accounts for an increase in EVD.

Analyzing how GE influences environmental deterioration in the CEMAC economies is equally important. The empirical results of the current study indicate that GE has a significant and positive impact on EVD in CEMAC countries. Hence, the outcome proved that a 1% rise in ineffective governance would cause an increase in EVD by 0.327% in the long term and 0.830%in the short-term. These results can be attributed to the fact that various government attitudes toward implementing and formulating proper initiatives and policies are ineffective in mitigating EVD. Again, transparency issues might also influence why GE contributes to EVD. Thus, transparency may be described as how rules and regulations are obeyed such that there is availability and direct accessibility of information. Moreover, we believe that environmental law is not adequately imposed by the government on firms to follow, which has led to a massive EVD in the CEMAC countries. Our research results contradict those [70,109]. However, our study supports this [2,69].

Moreover, the empirical findings illustrated that RQ positively correlates with EVD in the CEMAC regions. Therefore, based on the results presented in Table 7, a 1% expansion in RQ will eventually lead to an increase in EVD by 0.215% in the long term and 0.270% in the short-term. We can infer from these results that the CEMAC economies have weak institutional strategies for maintaining the environment. These findings further demonstrate the inadequacy of focusing on institutions by themselves to stop environmental deterioration. There is a need for other agents, such as individuals, households, enterprises, and stakeholders, to play an essential role in dissipating environmental EVD. For example, households can enhance clean energy in domestic activities, while enterprises can adopt modern environmental technology to utilize machinery in production. The research supports these existing studies that demonstrated a positive impact of RQ on EVD [110,111]. The study's outcome is inconsistent with those [23].

Congruent with previous studies [61,62,112], this research outcome further underlined that TI has an inverse interplay with EVD. Thus, the findings confirmed that a 1% rise in TI would mitigate EVD by 0.184% in the long term and 0.504% in the short-term. This outcome demonstrates to experience a continuous decline in EVD; the CEMAC countries may use modern technology to control EVD in these regions. Therefore, this study concludes that TI advancement supports the CEMAC economies agenda to achieve ecological stability as suggested by the STIRPAT model [17,87]. In addition [112], indicated that TI might help African countries switch from non-renewable energy sources to cleaner energy, lessening the dependence on natural gas. The usage of renewable energy, encouraged by TI, is therefore expected to lower estimates of the EVD in the CEMAC countries.

The empirical evidence is presented in Table 7, which demonstrates a negative and significant association between GSRD and EVD. If all other variables remain constant, a 1% influence on GRSRD activities decreases EVD by 0.452% in the long run and 0.721% in the short-run. Increased GSRD investment thus obviously implies reduced EVD in the CEMAC state. The scale effect of these analyses demonstrates that government support for research and development improves environmental sustainability. The results of our investigation agree with those of these studies, which reported a negative connection between GSRD and EVD [24–26]. However, our research is disputed by extant literature that argues that GSRD deteriorates the environmental quality and that EVD does not depend on the investment of GSRD [113,114]. The statistical value of R^2 of 0.98 demonstrates that the independent parameters have explained the shocks and variations in the explanatory variable of 98%. Moreover, Table 8 provides the robustness results from the FMOL, and DOLS approaches. The findings from the two approaches confirm the outcome of the *C*S-ARDL. Thus, the FMOLS and DOLS outcomes revealed that EGC, TI, and GSRD have an inverse association with EVD, while ENC, GE, and RQ contribute to a high level of EVD in the CEMAC regions.

4.6. Causality analysis

The Dumitrescu-Hurlin panel data causality test is presented in Table 9. This test provides policy directions to stakeholders and the government in promoting environmental sustainability. The D-H causality assessment outcome shows a unidirectional relationship between ENC, RQ, GE, and EVD. The implication is that every change in the economy's efficiency, government efficiency, energy regulation, and regulatory standards directly affects EVD in the CEMAC states. The outcome is in line with [47,115,116]. However, the causality assessment also showed a bi-directional relationship between EGC, TI, GSRD, and EVD. Programs and policies connected to these factors are determinants of dissipating EVD and promoting ecological sustainability in the CEMAC regions. These results concur with those [32,115,117].

5. Conclusion and policy directions

This research investigated the effect of EGC, ENC, GE, TI, RQ, and GSRD on EVD of the CEMAC emerging economies within the EKC and STIRPAT theory by evaluating panel data from 1990 to 2020. To ascertain the long-term estimates, we explore the CSD, heterogeneity, unit root test (CADF and CIPS), and cointegration test among the variables. The modern econometric technique, thus *C*S-ARDL, was applied to estimate the long-term elasticity coefficient between the regressors and the dependent variable. The study's findings highlighted that economic growth, technological innovation, and government spending on research and development help eradicate environmental degradation in the CEMAC regions. However, the study's empirical outcome proved that energy consumption, government effectiveness, and regulatory quality are detrimental to ecological well-being in these economies. The causality analysis indicated a one-way causality flowing from ENC, RQ, and GE to EVD. Moreover, EGC, TI, and GSRD have a bidirectional connection with EVD. Moreover, theoretically, this study supports the STIRPAT and EKC theory in CEMAC countries. Thus, the analysis revealed that environmental degradation could be dissipated through economic growth, technological innovation, and government spending on research and development.

5.1. Policy directions

In light of the above research findings, this research makes the following policy recommendations to the government and policymakers tasked with ensuring environmental sustainability in these economies.

First, given that the study findings demonstrated that EGC has an inverse connection with EVD, the study proposes that the CEMAC states must continue to establish appropriate initiatives and policies that would be utilized to simultaneously develop their economies and preserve the environment at the same time. Hence, for these countries to achieve ecological stability, this research suggests

Table 9
D-H causality test outcome.

Null Hypothesis	W − Statistics	Z − Statistics	Prob	Decision
lnEGC ⇎ lnEVD	6.217***	3.775	0.000	EGC ⟷ EVD
lnEVD ⇎ lnEGC	3.637***	1.361	0.000	
lnENC ⇎ lnEVD	3.983***	1.676	0.000	ENC → EVD
lnEVD ⇎ lnENC	1.083	0.094	0.924	
lnGE ⇎ lnEVD	15.603***	12.556	0.000	GE → EVD
lnEVD ⇎ lnGE	1.197	−0.921	0.356	
lnRQ ⇎ lnEVD	7.640***	5.106	0.000	RQ → EVD
lnEVD ⇎ lnRQ	0.872	−1.224	0.220	
lnTI ⇎ lnEVD	6.472***	4.248	0.000	TI ⟷ EVD
lnEVD ⇎ lnTI	4.173***	2.422	0.000	
lnGSRD ⇎ lnEVD	5.809***	3.393	0.000	GSRD ⟷EVD

Note: *** indicates 1% and 5% significance level, respectively, ⇎ does not granger cause, ⟷ bi-directional and → unidirectional.

adopting a greening policy for their economic expansion and working on sustainably modifying their current production and consumption habits. Second, since ENC was empirically established to humiliate environmental sustainability, this study suggests that the CEMAC countries diversify their energy production and usage to cleaner energy to overturn the downward trajectory of the inverse association of ENC with environmental quality.

Third, our study results demonstrated that GE causes environmental deterioration and havoc in the CEMAC economies. Therefore, this research suggests that various governments develop appropriate regulations to avoid any negative externalities leading to higher emissions and address public concerns about environmental deterioration. Government should pay critical attention to the plea of the civil group or political pressures in formulating and implementing quality plans and policies toward protecting the environment. Fourth, given the positive effect of regulatory quality on EVD, more environmental laws and regulations are required in the CEMAC economies to combat climate change. Furthermore, since RQ causes an increase in environmental pollution management, the CEMAC economies must tighten their ecological laws to reduce EVD progressively.

Fifth, the results from this analysis espoused that TI contributes enormously to the mitigation of EVD. Hence, the study outlines that stakeholders and policymakers should prioritize improving environmental-related technologies, allowing these economies to slow the rate of EVD. Moreover, industries and manufacturing firms should be encouraged to adopt environmentally friendly equipment for their production process. Last but not least, it was discovered that GSRD had an inverse impact on environmental degradation in the CEMAC nations. Therefore, we advise governments to keep funding research and development because it helps slow EVD. In addition, this outcome indicates that EVD and air quality are impacted by GSRD changes both instantly and over time. While promoting environmental innovation, governments can do so without limiting the expansion of the manufacturing industry.

5.2. Limitations and future directions

There is a certain limitation to this analysis. First, the current study findings were derived from an econometric evaluation of a few variables over a brief period (i.e., 1990–2020). Future research may examine parameters such as globalization, urbanization, the rule of law, etc., which affect EVD from different jurisdictions using the most recent dataset. Additionally, the analysis can be expanded to developing nations using other econometric approaches to examine the relationships between the variables that impact EVD. Researchers can use updated time series to explore the economic dynamics of alternative energy sources while accounting for structural discrepancies in the data. Finally, endogeneity constraints in the datasets can be rectified, and the current model can be elaborated upon using dynamic panel techniques.

Data availability

WID: https://databank.worldbank.org/source/world-development-indicators#
OECD: https://data.oecd.org/envpolicy/patents-on-environment-technologies.htm.
WGI: https://info.worldbank.org/governance/wgi/

Declaration of competing interest

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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