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Co-Integration Analysis of the Relationship between Economic Growth and CO_2 Emissions in the Countries of the East African Community

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Abstract

This paper explores the relationship between economic growth and CO_2 emissions in East African Community (EAC) countries between 1992 and 2020, in response to climate commitments including the Paris Agreement. Using an ARDL model, the study captures the short- and long-term effects of variables specifically the Gross Domestic Product (GDP), the energy consumption, and the industrialization. The results show an inverted U-shaped relationship: CO_2 emissions increase with economic growth up to a certain threshold and then decrease beyond that income level. In the short term, an economic growth increases emissions in some countries but in the long term, it is positively correlated with increased emissions. This study highlights the need for sustainable policies that maintain suitable agricultural and industrial practices while enabling economic growth that matches well with climate goals.

Keywords

Economic Growth, CO_2 Emissions, Sustainable Development

1. Introduction

It is generally acknowledged that economic growth is a prime objective for developing countries since it is considered a vital asset for socio-economic development and improved living conditions of the population. However, economic growth often goes along with an increase in CO_2 emissions, primarily due to the combustion of fossil fuel like coal, oil, and natural gas for example, which are widely used to power industries, transportation, and electricity generation [1].

The global warming caused by accumulation of Greenhouse gases (GHGs), the main one being the carbon dioxide (CO_2), is the primary threat to the humanity and could cost the global economy up to $550 billion (Stern, 2006 quoted by [2]), if governments do not take drastic measures. Climate experts now agree that Greenhouse Gases (GHGs) emissions due to all human activities, in particular the increasing use of fossil fuels, represent a growing and serious risk to the environment and the society.

As stated by literature, there are different approaches and hypotheses regarding the relationship between economic growth and environment pollution. On the one hand, it is found that the state of the environment quality is influenced by per capital income, which generates changes in the environmental policies, and supports the hypothesis showing that the more per capital income is high the more it leads to better environmental quality. On the other hand, the more per capital income is high the more it leads to greater environmental degradation [3].

According to the environmental curve hypothesis of Kuenets (ECK), economic growth meets this condition. Indeed, the ECK suggests that there is an inverted U-shaped relationship between environmental degradation and per capital income [4]. Then, beyond a certain level of per capital income, economic growth will result in improving the environment [1].

For authors like [5] and [6], environmental degradation is primary due to economic activity (production and consumption), which leads to the depletion of natural resources, the accumulation of waste, and the concentration of pollutants that exceed the biosphere's capacity. On the other side, [7] demonstrates a strong correlation between income and environmental protection measures. He shows that in the long-term, economic growth is the best way to guarantee improvement in environment quality. [8] also highlights the importance of environmental factors such as energy efficiency and the adoption of appropriate technologies to control the relationship between economic growth and CO_2 emissions in developing countries? This aspect is particularly relevant for the EAC countries, which must meet the challenges of reconciling their objectives for economic development with environmental sustainability goals.

The relationship between economic growth and carbon dioxide CO_2 emissions is a major concern topic in the context of sustainable development. According to [9], economic activities like industrialization and energy consumption are often linked with increased CO_2 emissions, which can have negative impacts on the environment.

In the context of the East African Community (EAC), an information gap persists regarding the conceptual basis of the sustainability of natural capital versus economic capital. This gap is extended by a lack of understanding of the theoretical foundations of the relationship between the dynamics of economic growth and the quality of landscape environment, particularly in terms of CO_2 emission levels, in order to foster economic emergence in developing countries. Consequently, this complex relationship deserves a particular attention as the region is experiencing rapid economic growth while being vulnerable to the impacts of climate change [10].

For that reason, in the light of concerns related to the framework of economic growth and the fact that the growth of many national economies cannot be limited by an increase in greenhouse gas emissions, we are studying a vital issue related to climate change, namely the relationship between economic growth and the CO_2 emissions in the EAC countries.

From this scientific perspective, the main question that we are led to ask is: What is the co-integration relationship between economic growth and CO_2 emissions in the East African Community (EAC)?

The aim is therefore to deepen the understanding of the conceptual basis of sustainability and to analyze, using the autoregressive model with staggered lags, the theoretical foundations pf the relationship between economic growth and quality of environmental in East Africa.

More specifically, this analytical study aims to:

- To explore synthetically the theoretical foundations of the sustainability of natural and economic capital in developing countries;
- To develop a conceptual framework for analyzing the relationship between economic growth and CO_2 emission levels based on economic and environmental variables choice;
- To measure, using an autoregressive model with staggered lags, the increase in the production of goods and services in EAC economies in relation to the dynamic of their CO_2 emissions.

2. Methodological Approach

The methodology adopted for addressing our problem is the Autoregressive Distributed lag (ARDL) model, developed by [11] and enhanced by [12]. Several factors motivated the choice of this model. First, this method is more suitable for small sample sizes [12], which is the case for this analysis. Second, this test can be used in case of non-stationary time series without the constraint of a consistent integration order, unlike other tests. Furthermore, this model allows addressing simultaneously the short-term effect and the long-term dynamics. The ARDL model is particularly useful in the context of time series, where it helps to understand how changes in one variable influence another over different periods.

If we consider the dependent variable "Y_t" and the independent variable "X_t", we will have:

- Autoregressive models (AR): These are dynamic models where, among the explanatory variables (X_t), we find the lagged dependent variable (its past values). In general, they are presented as follows (implicit form):

$$Y_t = \left(Y_{t-p}\right) \tag{1a}$$

- Distributed Lag (DL) models: these are dynamic models whose explanatory variables are: X_t and its past or lag values. In general, their form is:

$$Y_t = \left(X_{t-q}\right) \tag{1b}$$

The word (staggered lags) shows that short-term effects of X_t on Y_t are different from the long-term effects. From one tie point to another, the scale of Y_t's response to the change in X_t differs.

Autoregressive models with staggered lags (ARDL): these models combine the characteristics of two previous models. They include, among the explanatory variables (X_t), the lagged dependent variable (Y_{t-p}) and the past values of the independent variable (X_{t-}). They have the following general form:

$$Y_t = \left(Y_{t-p}, X_{t-q}\right) \tag{1c}$$

And, it is important to keep remember that the variables considered in these models must be stationary to avoid spurious regressions. In its general (explicit) form, an ARDL model is written as follows:

$$Yt = \varphi + a_1 Y_{t-1} + a_p Y_{t-p} + b_o X_t + \ldots b_q X_{q-t} + \varepsilon_t \quad \text{or again} \tag{1d}$$

$$Yt = \varphi + \sum a_i Y_{t-i\,p} i = 1 + \sum b_j X_{j-t\,q}\; j = 0 + \varepsilon \tag{2}$$

With $\varepsilon t \sim (0, \sigma)$: error term; "$b_0$" represents the short-term effect of X_t on Y_t. if we consider the following long-term or equilibrium relationship, "$Y_t = k + \varnothing X_t + u$", we can calculate the long-term effect of on (*i.e.* "$\varnothing$") as follows:

$$\varnothing = \sum b_j \Big/ \left(1 - \sum a_i\right) \tag{3}$$

As with for any dynamic model, the information criteria (AIC, SIC et HQ) will be used to determine the optimal lag (p^* or q^*). An optimal lag is one whose estimated model provides the minimum value of one of the stated criteria: the Akaike (AIC) lag, the Schwarz (SIC) lag, and the Hannan and Quinn (HQ) lag. Their values are calculated as follows:

$$A(p) = \log|\Sigma| + \frac{2}{T} n^2 p \tag{4}$$

$$A(p) = \log|\Sigma| + \frac{\log T}{T} n^2 p \tag{5}$$

$$HQ(p) = \log|\Sigma| + \frac{2 \log T}{T} n^2 p\,. \tag{6}$$

With: Σ = variance-covariance matrix of the estimated residuals; T = number of observations; p = lag of the estimated model; and n = number of regressors.

3. Results and Discussion

In this section, we first display the variable graphical analysis of the study, followed by the descriptive statistics analysis and the correlation test. Next, the stationarity of the series is validated before moving consecutively to the estimate and accuracy of the model, correlation and causality, short-term effects, and long-term dynamics. Finally, recommendations are provided.

3.1. Graphical Analysis

Figure 1 displays a summary of the graphs showing the dynamic curves of changes in CO_2 emission levels covering the period from 1990 to 2020 in East Africa.

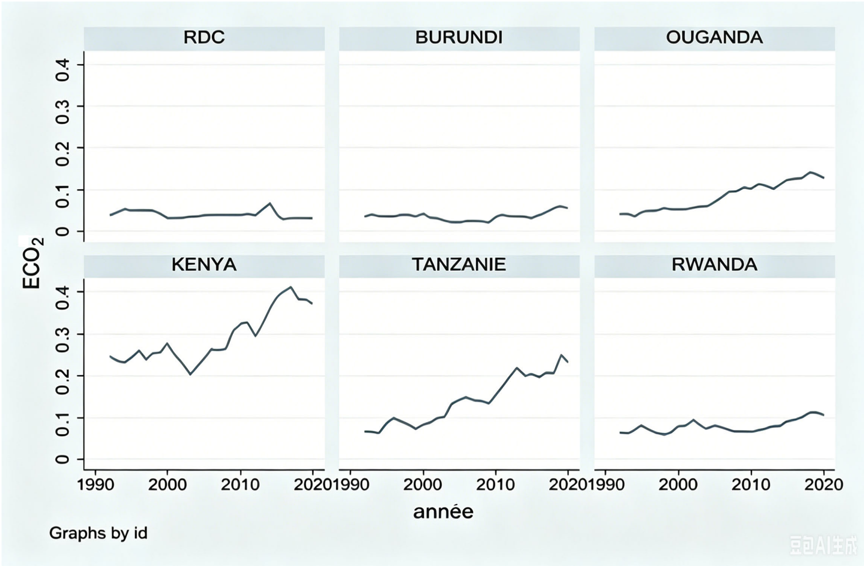

Figure 1. Evolution of CO_2 emissions in EAC country members.

This graph shows the evolution of CO_2 in the EAC country members. It appears to be linear in some countries like Tanzania, Kenya, and Uganda. CO_2 emissions increase over the years.

3.2. Correlation Test of Variables

Table 1 is a correlation matrix between the variables studied and shows the synthesis of the correlation test carried out using the STATA analysis software.

Table 1. Correlation test result.

	ECO_2	PIB	CONSENER	DEMO	VAINDU	SUPF	DPOP	SUPA
ECO_2	1							
PIB	0.7966	1						
CONSENER	0.0713	−0.1212	1					
DEMO	−0.0246	0.0089	0.1905	1				
VAINDU	0.7153	0.9024	0.0574	0.0335	1			
SUPF	−0.2759	−0.1848	0.3185	0.0812	0.1131	1		
DPOP	−0.3107	−0.1151	−0.6042	−0.0484	−0.4017	−0.5717	1	
SUPA	0.4616	0.3503	0.3067	0.0904	0.5814	0.5659	−0.8721	1

Source: our analysis using Stata.

ECO_2 (CO_2 Emissions): Strongly correlates with GDP (0.7966) and industrial value added (0.7153) showing that countries with larger economies and a strong industrial activity tend to emit more CO_2. Positively correlated with the agricultural area (0.4616); suggesting that the expansion of agricultural lands may be linked to an increase in CO_2 emissions. Negatively correlated with the population density (−0.3107) and the forest area (−0.2759), suggesting that regions with higher population densities and more forests tend to emit less CO_2.

3.3. Stationarity Test

Considering the dynamics of the variables studied, we selected the Augmented Dickey-Fuller (ADF) test, which is effective in cases of autocorrelation of errors, and the W-t-bar test, which is effective in cases of structural disruption or regime change. The results of these tests are presented in Table 2 below.

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Table 2. Stationarity results of non-stationary series at level.

	First difference stationarity test for non-stationary variables at level			
	Im-Pesaran-Shin unit-root test			
	H0: All panels contain unit roots			Number of panels = 6
	Ha: Some panels are stationary			Number of periods = 28
	AR parameter: Panel-specific			Asymptotics: T,N → Infinity
	Panel means: Included			Sequentially
	Time trend: Not included			
	ADF regressions: 1 lag			
Variable	**Statistic**		**p-value**	**Decision**
ECO_2	W-t-bar	−5.6445	0.00000	Stationary
PIB	W-t-bar	−6.1621	0.00000	Stationary
CONSENER	W-t-bar	−4.8235	0.00000	Stationary
VAINDU	W-t-bar	−5.4455	0.00000	Stationary
SUPF	W-t-bar	0.4354	0.66840	Non-stationary
DPOP	W-t-bar	−1.8647	0.03110	Stationary
SUPA	W-t-bar	−3.7287	0.00010	Stationary

Table 3. Stationary results of the series.

	Unit root tests at levels for all variables	
	Im-Pesaran-Shin unit-root test	
	H0: All panels contain unit roots	Number of panels = 6
	Ha: Some panels are stationary	Number of periods = 29
	AR parameter: Panel-specific	Asymptotics: T,N → Infinity
	Panel means: Included	Sequentially
	Time trend: Not included	
	ADF regressions: 1 lag	

Continued

Variable	Statistic		p-value	Decision
ECO_2	W-t-bar	1.1531	0.87560	Non-stationary
PIB	W-t-bar	3.4003	0.99970	Non-stationary
CONSENER	W-t-bar	0.8350	0.79810	Non-stationary
DEMO	W-t-bar	−6.4475	0.00000	Stationary
VAINDU	W-t-bar	6.0450	1.00000	Non-stationary
SUPF	W-t-bar	3.2930	0.99950	Non-stationary
DPOP	W-t-bar	7.5155	1.00000	Non-stationary
SUPA	W-t-bar	1.1587	0.87670	Non-stationary

Table 3 shows the Augmented Diskey-Fuller (ADF) stationary test at level for all variables.

Results interpretation for each variable:

ECO_2: The W-t-bar statistic is 1.1531 with a p-value of 0.87560, since the p-value is greater than 0.05, we cannot reject H_0. The **ECO_2** series is non-stationary, **GDP:** The W-t-bar statistic is 3.4003 with a p-value of 0.99970. Given that the p-value is greater than 0.05, we cannot reject H_0. The GDP series is non-stationary, CONSENER: The W-t-bar statistic is 0.8350 with a p-value of 0.79810. Considering that the p-value is greater than 0.05, we cannot reject H_0. The CONSENER series is non-stationary, DEMO: The W-t-bar statistic is −6.4475 with a p-value of 0.00000. Since the p-value is less than 0.05, H_0 is rejected. The DEMO series is stationary, VAINDU; The W-t-bar statistic is 6.0450 with a p-value of 1.00000. Considering that the p-value is greater than 0.05, we cannot reject H_0. The VAINDU series is non-stationary, SUPF: The W-t-bar statistic is 3.2930 with a p-value of 0.99950. Given that the p-value is greater than 0.05, we cannot reject H_0. The SUPF is non-stationary, DPOP: The W-t-bar is 7.5155 with a p-value of 1.00000. Since the p-value is greater than 0.05, we cannot reject H_0. The DPOP series is non-stationary, SUPA: The W-t-bar statistic is 1.1587 with a p-value of 0.87670. Since the p-value is greater than 0.05, we cannot reject H_0. The SUPA series is non-stationary.

Among the variables tested, only the DEMO series is stationary. All other variables (ECO_2, GDP, CONSENER? VAINDU, SUPF, DPOP, SUPA) are non-stationary, meaning they contain unit roots and show non-stationary properties in the tested panels.

Table 2 shows the Augmented Dickey-Fuller (ADF) test of stationarity of non-stationary series at level.

It results from the panel data stationary analysis that the forest area variable is not stationary in terms of level or in terms of first difference. Therefore, it will not be included in the model that we will estimate. Indeed, the ARDL model only agrees with variables that are stationary at level and/or first difference. This allows us to perform co-integration tests and detect the long-term relationship between integrated variables of different orders without using spurious regressions.

3.4. Lags Selection (LAGS)

Table 4 shows the results of the selection of lags for all countries in the panel and all variables studied.

Table 4. Results of lags selection.

	(1) DRC	(2) BURUNDI	(3) UGANDA	(4) KENYA	(5) TANZANIA	(6) RWANDA
VARIABLES	leco2	leco2	leco2	leco2	leco2	leco2
L.leco2	0.150*	−0.799*	0.162	0.454*	0.671***	−0.157
	(0.0804)	(0.328)	(0.197)	(0.218)	(0.174)	(0.174)
L2.leco2		0.734***		−0.591**		−0.486**
		(0.198)		(0.203)		(0.178)
Lpib	−0.363	0.776	0.333***	0.155	−0.510	−1.011
	(0.330)	(0.455)	(0.105)	(0.213)	(0.444)	(0.918)
L.lpib		2.180**		0.234		0.0249
		(0.648)		(0.220)		(0.306)
L2.lpib				0.220		−0.458**
				(0.126)		(0.188)
Lconsener	−17.01***	−13.33***	−4.416	1.836	−8.789***	−4.089***
	(1.407)	(1.018)	−2.858	−1.658	(1.214)	(0.985)
L.lconsener		−10.68*	−10.82**		8.031***	1.377
		(4.959)	(4.028)		(1.480)	(1.132)
L2.lconsener		12.29***				−4.762***
		(3.113)				(1.453)
Ldemo	0.101	−0.349**	−1.033**	−0.383	0.00761	−0.271***
	(0.0927)	(0.102)	(0.368)	(0.228)	(0.0883)	(0.0788)
L.ldemo	−0.135	0.254**	−0.140			
	(0.0948)	(0.0903)	(0.335)			
L2.ldemo	0.245**	−0.221**	0.978***			
	(0.0920)	(0.0875)	(0.310)			
Lvaind	0.219	−0.642	−0.119***	−0.328**	0.499	1.113
	(0.290)	(0.421)	(0.0350)	(0.143)	(0.383)	(0.753)
L.lvaind	−0.107*	−1.966**	−0.104***			
	(0.0560)	(0.662)	(0.0292)			
L2.lvaind		0.654**	−0.111***			
		(0.209)	(0.0286)			
Lsupa	−0.738**	−3.753	8.919***	−0.706	5.486*	−1.042
	(0.300)	−2.136	−2.391	−1.946	−2.820	(0.686)

Continued

L.lsupa			−8.681**	5.767**	−5.782**	4.881***
			−3.127	−2.282	−2.633	−1.020
L2.lsupa			2.717			−1.820*
			−1.955			(0.982)
Constant	83.47***	112.4**	38.09**	−68.89*	−2.163	−6.225
	−7.694	(39.43)	(16.46)	(33.72)	(13.85)	(19.29)
Observations	27	21	27	27	27	23
Lags	(1, 0, 0, 2, 1, 0)	(2, 1, 2, 2, 2, 0)	(1, 0, 1, 2, 2, 2)	(2, 2, 0, 0, 0, 1)	(1, 0, 1, 0, 0, 1)	(2, 2, 2, 0, 0, 2)
R-squared	0.950	0.998	0.994	0.952	0.989	0.986

Source: performed by the author. Standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

This table allows us to gauge the ARDL models for each of the countries in our panel in order to determine the maximum number lags to adopt for our ARDL model in Panel. The Bayesien criterion information is used to select the optimal number of lags for each of the estimates made for each country.

3.5. Global Long-Term ARDL Model Estimation

Table 5 presents the result of the long-term model estimation.

Table 5. Result of the global long-term ARDL model estimation.

	(1)	(2)
VARIABLES	ECT	SR
ECT		−0.183***
		(0.0516)
D.lpib		−0.196*
		(0.108)
D.lconsener		−7.202***
		(2.330)
D.ldemo		0.0282
		(0.111)
D.lvaind		0.142**
		(0.0620)
D.lsupa		0.356
		(1.114)
lpib	1.550***	
	(0.411)	
lconsener	−7.599***	
	(1.476)	

Continued

ldemo	−0.219*	
	(0.119)	
lvaind	−0.965***	
	(0.302)	
lsupa	−1.422**	
	(0.606)	
Constant		11.27***
		(3.125)
Observations	160	160

Standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

1) Error Correction Term (ECT)

Coefficient ECT (−0.183)*: The coefficient of the error correction term is negative and significant at 1% (***) level. This indicates that the model adjusts for long-term imbalances. More specifically, a deviation from the long-term balance is adjusted by 18.3% in the following period. It means that when the dependent variable deviates from its long-term balance, it tends to get closer to that balance quite quickly (at a rate of 18.3% per period). The greatness of this correction suggests that the model has a constant dynamic, and that the variables included in the model are co-integrated. That is to say, they share a long-term balance relationship.

2) Long-Term Dynamics

The long-term coefficients reveal the balance relationships between variables.

lpib (1.550)*: This coefficient is positive and strongly significant (level 1% l, ***), demonstrating that in the long-term an increase in GDP is associated with an increase in CO_2 emissions. This confirms a positive long-term economic relationship where GDP growth leads to benefits or improvements for CO_2 emissions. **lconsener (−7.599)***: The coefficient is negative and highly significant, suggesting a strong negative long-term relationship between energy consumption and CO_2 emissions. In the long term, this can reflect the unfortunate effects of high energy consumption, like environmental costs, resources degradation, or impacts on well-being. **ldemo* (−0.219): This coefficient is negative and significant at 10% (*) level, indicating that in the long-term, an increase in demographic variables is associated with a slight decrease in CO_2 emissions. This suggests that some aspects of demographic changes, like population density or ageing, have a long-term negative impact on CO_2 emissions. **lvaind (−0.965)*** The coefficient is negative and significant at 1% (***) level, indicating a negative long-term relationship between the industrial added value and the CO_2 emissions. This indicates that excessive concentration of industry in long-term can have negative impacts, possibly due to environmental problems or the structural transformation of the economy. **lsupa (−1.422):** This coefficient is negative and significant at 5% (**) level, suggesting that in the long-term, an increase in agricultural area is associated with a decrease in CO_2 emissions. This can indicate the saturation effects or growth limits that occur when some factors increase beyond an optimal threshold.

3) Constant (11.27)*: The constant is significant at 1% (***) level, indicating a significant baseline value for the dependent variable at a long-term balance.

3.6. Short-Term ARDL Model Estimation per Country

Table 6 presents the results of the short-term model estimation by country.

Table 6. Short-term ARDL model estimation per country.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	ECT	DRC	BURUNDI	UGANDA	KENYA	TANZANIA	RWANDA
ECT		−0.234***	−0.338***	0.00297	−0.248***	−0.215**	−0.0670
		(0.0660)	(0.129)	(0.0268)	(0.0892)	(0.0902)	(0.0948)
D.lpib		−0.401***	−0.366	0.129	−0.0818	−0.511	0.0559
		(0.112)	(0.368)	(0.119)	(0.168)	(0.711)	(0.576)
D.lconsener		−14.70***	−10.13***	−8.333***	1.684	−8.534***	−3.197**
		(1.780)	(2.101)	(2.725)	(1.559)	(1.143)	(1.551)
D.ldemo		−0.106	−0.0109	−0.264	0.539	−0.0137	0.0241
		(0.0682)	(0.0295)	(0.295)	(0.452)	(0.0754)	(0.0412)
D.lvaind		0.298***	0.205	0.0175	0.174	0.254	−0.0987
		(0.114)	(0.390)	(0.0240)	(0.155)	(0.682)	(0.518)
D.lsupa		−0.684	−2.772**	0.127	−0.759	5.334***	0.891
		(0.818)	(1.411)	(1.808)	(1.524)	(2.066)	(0.754)
Lpib	1.550***						
	(0.411)						
Lconsener	−7.599***						
	(1.476)						
Ldemo	−0.219*						
	(0.119)						
Lvaind	−0.965***						
	(0.302)						
Lsupa	−1.422**						
	(0.606)						
Constant		14.88***	19.41**	−0.168	15.96***	13.68**	3.860
		(4.179)	(9.347)	(1.661)	(5.693)	(6.905)	(5.448)
Observations	160	160	160	160	160	160	160

Source: Performed by the author. Standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

The error correction coefficient (ECT) is −0.234 for DRC. This means there is a co-integrating relationship between our variables. This coefficient also informs that a long-term deviation is corrected at 0.234%. The same is true for Burundi where deviations are corrected at 0.338%, and 0.248% for Kenya, and 0.215% for Tanzania. However, for Uganda and Rwanda, this long-term relationship does not exist individually. For the DRC, in the short term, the GDP growth reduces CO_2 emissions to 1% threshold. For the other countries, this relationship is not significant.

For all countries, we can see that energy consumption decreases CO_2 emissions, except in Kenya where this relationship is not significant.

For the DRC, it can be observed that an increase in the added value of the industrial sector in the short-term increases CO_2 emissions. Though, this relationship is not significant for any of the other countries.

For Burundi, it can be noticed that increasing agricultural land area reduces CO_2 emissions in the short-term. However, for Tanzania, the effect in reversed. This is to say that any short-term increase in agricultural areas leads to an increase in CO_2 emissions. For the other countries, this relationship is not statistically significant.

The long-term relationship is identical for all countries as we can see from this table.

4. Discussion

Economic and environmental interpretation

To interpret the results, it is first necessary to refer to the co-integration tests that are performed as part of the analysis. Co-integration tests are used to determine whether there is a long-term relationship between economic growth and CO_2 emissions, that is, whether these two variables move jointly over an extended period. The tests results can indicate either a positive co-integration (the two variables are positively related) or a negative co-integration (the two variables are negatively related).

In case of positive co-integration, it means economic growth is associated with an increase in CO_2 emissions. This result is consistent with economic theories claiming that economic growth is often followed by increase in energy consumption and, as a result, carbon dioxide emissions. This interpretation underscores the importance of taking measures to reduce CO_2 emissions while promoting at the same time economic growth in order to join development with environment protection.

On the other hand, if tests reveal negative co-integration, this shows that there is an opposite relationship between economic growth and CO_2 emissions. In this case, economic growth is related to decrease in CO_2 emissions. This scenario is less common but it may reflect a trend towards a greener economy, characterized by more the use of more efficient resources, having recourse to renewable energy, and the use of sustainable production and consumption models. This interpretation suggests that economic growth can well match with CO_2 emissions reduction.

The results of this analysis show that there is a long-term inverted U-shaped relationship between GDP and CO_2 emissions. This means the CO_2 emissions increase as GDP increase until the inflection point where the CO_2 emissions gradually decrease.

Multivariate long-term effects of growth on CO_2 emissions

The results of the empirical analysis suggest an inverted U-shaped relationship between GDP and CO_2 emissions. That is, they agree with the environmental Kuzenets curve (EKC) hypothesis. Depending on this hypothesis, CO_2 emissions increase with economic growth until a certain point after which they decrease as incomes continue to increase. This observation agrees with the studies by [13] and [14] who also found an inverted U-shaped relationship between economic growth and environmental degradation. However, it is important to mention that the validity of CEK in EAC countries is contextual and may vary depending on each country's economic policies, development level, and economic structure.

The results demonstrate noteworthy differences between the short-term and the long-term effects of economic growth on CO_2 emissions. In the short-term, an increase in GDP is related to a reduction of CO_2 emissions in some countries like DRC. This can be ascribed to investments in suitable technologies or transition to less polluting energy sources. Nevertheless, in the long-term, economic growth positively correlates with CO_2 emissions, showing that continued growth can lead to increased emissions if it remains based on intensive carbon activities. These results are consistent with [1] who emphasizes that economic growth effect on the environment depends on factors like energy efficiency, environmental policies, and the typesetting of the economic sector.

The study reveals that energy consumption and industrial added value are important determinants of CO_2 emissions. Energy consumption tends to reduce emissions in almost all the countries studied with exception of Kenya. This suggests that more efficient energy is used in these countries. This contrasts with the findings of [15] who found that energy consumption was generally associated with an increase in CO_2 emissions. The development level and the energy mix of the EAC countries where the use of renewable energies is widespread can explain the difference. However, the industrial added value is linked to an increase in CO_2 emissions in the short-term. It highlights the need to promote more sustainable industrial practices and uphold the adoption of appropriate technologies.

The results also show that population growth, population density, forest area, and the expansion of agricultural areas have complex effects CO_2 emissions. Population growth is always associated with increased energy demand, leading to higher emissions. Nevertheless, long-term effects show a negative relationship between these variables and CO_2 emissions; suggesting that factors like improved agricultural practices, energy efficiency, and forest protection play a role in reducing emissions. This agrees with the work of [16] and [17] which emphasize the importance of sustainable agricultural practices and land management to mitigate climate change.

Political and environmental implications.

The results of this study call for an in-depth examination of how EAC countries can reconcile economic growth with CO_2 emissions decrease. The findings suggest that continued economic growth in the region can lead to increased emissions unless measures are taken to improve energy efficiency, promote renewable energy, and encourage sustainable agricultural and industrial practices. This aligns with the conclusions of ecological upgrading theory and [18] which states that strict environmental policies and technological innovation can enable economic growth while protecting the environment.

In conclusion, this study underscores the importance of implementing sustainable development policies in EAC countries. Government is encouraged to invest in suitable technologies, promote sustainable agricultural practices, and strengthen environmental policies in order to achieve a balance between economic development and environmental protection. It is also fundamental to adopt an integrated regional approach to enable the sharing of best practices and the coordination of efforts to mitigate CO_2 emissions.

5. Conclusion, Recommendations and Perspectives

This study analyzed the complex relationship between economic growth and CO_2 emissions in East African Community (EAC) countries for the period between 1992 and 2020. Using a ARDL model, we captured short-term and long-term dynamics to understand how GDP growth, energy consumption, industrialization, and other factors influence CO_2 emissions. Results highlight an inverted U-shaped relationship, suggesting that emissions increase with economic growth up to a certain point. Then,

In the short-term, GDP growth in some countries helps reduce emissions, especially in DRC, while energy consumption has a variable impact depending on national contexts. However, in the long-term, continued GDP growth correlates with increased CO_2 emissions, illustrating the challenge facing the EAC countries in reconciling development.

These findings highlight the importance of sustainable development policies in determining economic growth, mainly in reducing dependence on fossil fuels. Governments in the region are encouraged to invest in proper technologies, promote sustainable agriculture and industrial practices, and strengthen environmental regulations. Such measures are likely to enable a transition to a less polluting growth model that is more resilient to climate challenges.

For future research, it would be relevant to include analyses of other environmental impacts and to consider specific economic sectors in to understand better this relationship and guide appropriate public policies. Ultimately, this study contributes to global efforts to limit global warming while meeting development needs.

Authors' Contributions

Role of the contributor	Names of authors
Conceptualization	MURHULA SAFARI Alliance, NGENDAKUMANA Serge
Data Management	MURHULA SAFARI Alliance
Formal analysis	NGENDAKUMANA Serge
Survey and investigation	MURHULA SAFARI Alliance
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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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