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Testing the Environmental Kuznets Curve Hypothesis in Madagascar:

Empirical evidence using the ARDL approach

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Abstract

This study investigates whether the classical Environmental Kuznets Curve (EKC) exists in Madagascar using annual data from 1990 to 2015. Employing the autoregressive distributed lag (ARDL) approach and Granger causality tests, we examine the relationships between CO₂ emissions, economic growth, agricultural production, and trade openness. Results show that economic growth follows a U-shaped pattern with CO₂ emissions: emissions decline at low income levels but increase as income rises, indicating that the classical inverted U-shaped EKC is not present. Agricultural production has no significant effect, and trade openness has a marginally negative impact on emissions. Granger causality tests indicate a unidirectional effect from economic growth to emissions. Policy recommendations focus on promoting cleaner trade and investing in renewable energy to prevent emissions from rising at higher income levels.

Keywords: EKC Hypothesis, Carbon Dioxide Emissions, Economic Growth, ARDL, Granger Causality, Madagascar

JEL Classifications: C32, O44, O55, Q53

1 Introduction

Economic growth is often accompanied by environmental degradation, posing a critical challenge for developing nations like Madagascar, where economic development is vital yet environmental sustainability is increasingly threatened by climate change impacts [13]. The Environmental Kuznets Curve (EKC) hypothesis posits that environmental degradation initially worsens with economic growth but improves beyond a certain income threshold, forming an inverted U shaped relationship [5, 7]. However, empirical evidence on the EKC is mixed, with some studies identifying alternative patterns, such as U-shaped curves, in low income countries [11, 8]. Madagascar, a biodiversity hotspot with a predominantly agrarian economy and growing trade openness, provides a unique context to test the EKC hypothesis, particularly given its vulnerability to environmental degradation and limited contribution to global emissions [6].

The research problem lies in understanding whether economic growth in Madagascar follows the classical EKC pattern or exhibits a distinct trajectory, and how factors like agricultural production and trade openness influence CO₂ emissions. Previous studies, such as [6] in Somalia, confirm an inverted U shaped EKC, but Madagascar's unique economic structure marked by subsistence agriculture and reliance on raw material exports may yield different dynamics [3]. Additionally, the causal relationships between

economic growth, agriculture, trade, and emissions remain underexplored in this context, necessitating rigorous econometric analysis [4].

This study tests the following hypotheses:

1. **H1:** Economic growth ($\ln\text{GDP}$, $\ln\text{GDP}^2$) exhibits a non-linear relationship with CO_2 emissions ($\ln\text{CO}_2$). Unlike the classical EKC, emissions may initially decrease and then increase, forming a U-shaped pattern.
2. **H2:** Agricultural production ($\ln\text{Agri}$) influences CO_2 emissions, either positively or negatively, depending on its emission intensity.
3. **H3:** Trade openness ($\ln\text{Trade}$) reduces CO_2 emissions by facilitating cleaner technology transfers.
4. **H4:** There exists a causal relationship between economic growth ($\ln\text{GDP}$, $\ln\text{GDP}^2$) and CO_2 emissions, as well as between agriculture, trade, and emissions.

This study employs the ARDL approach and Granger causality tests to examine these hypotheses, contributing to the literature on environmental economics in low-income African nations.

2 Methodology

The methodology draws on the work of Hussein and Warsame [6], which employs an ARDL approach to test the EKC hypothesis in the case of Somalia.

2.1 Data and variables

This study uses annual time-series data from 1990 to 2015 to test the EKC hypothesis in Madagascar. The dependent variable is the natural logarithm of CO_2 emissions ($\ln\text{CO}_2$), representing environmental degradation. Independent variables include the natural logarithm of real GDP ($\ln\text{GDP}$), its square ($\ln\text{GDP}^2$), agricultural production ($\ln\text{Agri}$), and trade openness ($\ln\text{Trade}$). Lagged terms

($L(\ln\text{CO}_2, 1)$, $L(\ln\text{GDP}, 1)$, $L(\ln\text{GDP}, 2)$) capture dynamic effects in the ARDL model. Data are sourced from reputable international databases, consistent with [6].

2.2 Econometric approach

The ARDL bounds testing approach [9] examines long-run and short-run relationships between CO_2 emissions and explanatory variables, suitable for small samples and variables integrated of order $I(0)$ or $I(1)$. Granger causality tests [4] explore directional relationships. The analysis involves:

1. **Unit Root Tests:** Augmented Dickey-Fuller (ADF) tests ensure variables are stationary at levels ($I(0)$) or first differences ($I(1)$), excluding $I(2)$ variables.
2. **Bounds Test:** The F-test assesses long-run cointegration by comparing the F-statistic to critical bounds [9].
3. **Coefficient Estimation:** Long-run and short-run coefficients are estimated, with the error correction term (ECT) indicating adjustment speed.
4. **Granger Causality Tests:** Tests with two lags assess whether lagged values of one variable predict another.
5. **Diagnostic Tests:** Breusch-Godfrey and Jarque-Bera tests check for serial correlation and normality, respectively. The CUSUM test ensures model stability.

2.3 Model specification

The autoregressive distributed lag (ARDL) model is specified as follows based on the work of Hussein [6], where both the dependent variable and selected regressors enter with lags to capture the dynamic adjustment process:

as indicated by a test statistic of -2.2307 ($p = 0.0357$), suggesting an I(0) process at the 5% level.

$$\ln(\text{CO}_2)_t = \beta_0 + \beta_1 \ln(\text{CO}_2)_{t-1} + \beta_2 \ln(\text{GDP})_t + \beta_3 \ln(\text{GDP})_t^2 + \beta_4 \ln(\text{Agri})_t + \beta_5 \ln(\text{Trade})_t + \beta_6 \ln(\text{GDP})_{t-1} + \beta_7 \ln(\text{GDP})_{t-2} + \varepsilon_t$$

Table 1: Résultats du test ADF (racine unitaire)

Variabl ⁽¹⁾	Statistique	Valeur critique (5%)	Ordre
$\ln(\text{CO}_2)$	-0.6713	-2.93	I(1)
$\ln(\text{GDP})$	-0.4707	-2.93	I(1)
$\ln(\text{GDP})^2$	-0.4511	-2.93	I(1)
$\ln(\text{Trade})$	-1.7422	-2.93	I(1)
$\ln(\text{Agri})$	-2.2307*	-2.93	I(0)

Note: * indicates statistical significance at the 5% level. The variable is stationary in levels (I(0)).

where:

- $\ln(\text{CO}_2)_t$ is the natural logarithm of per capita carbon dioxide emissions at time t ,
- $\ln(\text{GDP})_t$ is the natural logarithm of real GDP per capita,
- $\ln(\text{GDP})_t^2$ is the squared term of $\ln(\text{GDP})_t$, used to capture potential non-linearities (EKC hypothesis),
- $\ln(\text{Agri})_t$ represents the natural logarithm of agricultural value added,
- $\ln(\text{Trade})_t$ is the natural logarithm of trade openness (exports plus imports as a percentage of GDP),
- $\ln(\text{GDP})_{t-1}$, $\ln(\text{GDP})_{t-2}$ are the first and second lags of GDP per capita respectively,
- $\ln(\text{CO}_2)_{t-1}$ is the lagged dependent variable,
- ε_t is a white noise error term.

3 Results

3.1 Unit Root Tests

The stationarity properties of the variables were assessed using the Augmented Dickey-Fuller (ADF) test. As reported in Table 1, most variables—namely, $\ln\text{CO}_2$, $\ln\text{GDP}$, $\ln\text{GDP}^2$, and $\ln\text{Trade}$ —exhibit non-stationarity at level but become stationary after first differencing, thereby following an I(1) process. Specifically, their test statistics are as follows: $\ln\text{CO}_2$ (-0.6713, $p = 0.509$), $\ln\text{GDP}$ (-0.4707, $p = 0.642$), $\ln\text{GDP}^2$ (-0.4511, $p = 0.656$), and $\ln\text{Trade}$ (-1.7422, $p = 0.0948$). In contrast, $\ln\text{Agri}$ is stationary in levels,

3.2 Bounds cointegration test

To examine the presence of a long-run relationship among the variables, the bounds testing procedure (under Case III: unrestricted intercept with no trend) was implemented. As shown in Table 2, the computed F-statistic is 4.7434 ($p = 0.016$), which exceeds the upper critical bound at the 5% significance level and even at 1%. This outcome provides strong evidence in favor of cointegration, indicating the existence of a stable long-run relationship among the modelled variables.

Table 2: Bounds Cointegration Test (Case III: unrestricted intercept and no trend)

Significance Level	Lower Bound	Upper Bound
10%	2.20	3.09
5%	2.56	3.49
1%	3.29	4.37
F-statistic	4.7434** ($p = 0.016$)	

Note: ** $p < 0.05$

3.3 Granger causality tests

Table 3 summarizes the results of Granger causality tests conducted with a lag length of two. The results suggest that both $\ln\text{GDP}$ and its squared term ($\ln\text{GDP}^2$) Granger-cause $\ln\text{CO}_2$ emissions at the 10% significance level, with F-statistics of 2.8327 ($p = 0.0814$) and 2.8756 ($p = 0.0787$), respectively. However, there is no statistically significant evidence of

causality running from $\ln CO_2$ to either $\ln GDP$ or $\ln GDP^2$. Similarly, no significant causality is detected between $\ln CO_2$ and either $\ln Agri$ or $\ln Trade$, in either direction.

Table 3: Granger Causality Test Results (Lag = 2)

Null Hypothesis	F-stat.	p-value	Signif.
$\ln GDP \rightarrow \ln CO_2$	2.83	0.0814	*
$\ln CO_2 \rightarrow \ln GDP$	1.45	0.2571	
$\ln GDP^2 \rightarrow \ln CO_2$	2.88	0.0787	*
$\ln CO_2 \rightarrow \ln GDP^2$	1.42	0.2636	
$\ln Agri \rightarrow \ln CO_2$	1.87	0.1795	
$\ln CO_2 \rightarrow \ln Agri$	0.21	0.8118	
$\ln Trade \rightarrow \ln CO_2$	0.80	0.4614	
$\ln CO_2 \rightarrow \ln Trade$	2.26	0.1290	

Signif. levels: * $p < 0.01$, * $p < 0.05$, $p < 0.10$

3.4 ARDL estimates: long and short run dynamics

The results of the ARDL model are presented in Table 4, based on 26 observations. The model exhibits high explanatory power ($R^2 = 0.955$; adjusted $R^2 = 0.937$). In the short run, emissions show strong inertia, with the lagged dependent variable $\ln CO_{2,t-1}$ being highly significant (coefficient = 0.50, $p = 0.001$). Economic growth exerts a nonlinear effect on emissions: while $\ln GDP$ is associated with a significant reduction in emissions (coefficient = -28.18, $p = 0.031$), its squared term is positively and significantly associated with emissions (coefficient = 0.63, $p = 0.029$), thus supporting the Environmental Kuznets Curve (EKC) hypothesis.

Agricultural output ($\ln Agri$) appears to have no statistically significant impact ($p = 0.734$), suggesting a negligible short-run effect. Conversely, trade openness ($\ln Trade$) has a negative effect on emissions that is weakly significant at the 10% level (coefficient = -0.29, $p = 0.090$), partially supporting the pollution haven or efficiency channel hypotheses.

Table 4: ARDL Model: Long- and Short-Run Coefficient Estimates

Variable	Estimate	95% CI	p-value
Constant	311.14	[37.23 ; 585.05]	0.028**
$L(\ln CO_2, 1)$	0.50	[0.22 ; 0.77]	0.001*
$\ln GDP$	-28.18	[-53.53 ; -2.82]	0.031**
$L(\ln GDP, 1)$	-0.28	[-0.76 ; 0.20]	0.234
$L(\ln GDP, 2)$	0.28	[-0.12 ; 0.68]	0.156
$\ln GDP^2$	0.63	[0.07 ; 1.18]	0.029**
$\ln Agri$	0.30	[-1.54 ; 2.15]	0.734
$\ln Trade$	-0.29	[-0.63 ; 0.05]	0.090*
$R^2 / \text{Adj. } R^2$		0.955 / 0.937	

Significance levels: * $p < 0.01$, * $p < 0.05$, $p < 0.10$

3.5 Diagnostic tests

Model diagnostics support the reliability of the ARDL estimation. The Breusch-Godfrey LM test (LM = 1.0133, df = 2, $p = 0.6025$) reveals no evidence of serial correlation. Residuals are normally distributed, as indicated by the Jarque-Bera test ($\chi^2 = 3.6321$, df = 2, $p = 0.1627$). Moreover, the stability of the model over time is confirmed by the CUSUM test, which lies within the 5% confidence bounds.

4 Discussion

The analysis does not confirm the classical inverted U-shaped EKC. Instead, a U-shaped relationship between economic growth and CO_2 emissions emerges for Madagascar: emissions decrease at low levels of GDP but increase as GDP rises. This atypical pattern may reflect an initial transition from traditional biomass use to less polluting activities, followed by higher emissions driven by industrialization and energy consumption [10].

Granger causality tests support H4 partially, showing unidirectional causality from $\ln GDP$ and $\ln GDP^2$ to $\ln CO_2$, but not in the reverse direction. This suggests that economic growth is the primary driver of environmental outcomes in the Malagasy context, consistent with Stern [13] and in contrast to bidirectional causality observed in OECD countries [2].

Agricultural production is insignificant, rejecting H2, likely due to Madagascar's subsistence agriculture and low mechanization levels. Trade openness shows a weakly negative effect on emissions, offering limited support for H3 and aligning partially with the pollution halo hypothesis [1, 12]. The weak causality from trade reflects Madagascar's export structure, dominated by raw materials [3].

Overall, the observed U-shaped pattern underscores that economic growth alone does not automatically improve environmental quality in low-income countries. Policy interventions are needed to prevent emissions from rising as income increases.

5 Conclusion

This study provides evidence of a U-shaped relationship between economic growth and CO₂ emissions in Madagascar, indicating that emissions initially decline at low income levels but increase beyond a certain GDP threshold. The classical inverted U-shaped EKC is not confirmed. Economic growth drives emissions unidirectionally, while agricultural production has negligible impact and trade openness has a marginally negative effect.

Policy implications include promoting environmentally friendly trade, investing in renewable energy, and implementing structural reforms to reduce emission intensity, particularly in the industrial and energy sectors. Given the limited role of agriculture, mitigation strategies should target sectors with higher emission potential. Future research should extend the dataset and include additional variables, such as energy consumption and urbanization, to better understand the environmental dynamics in Madagascar.

5.1 Limitations

The small sample (26 observations) limits statistical power compared to Somalia's 1980–2018 data [6]. Excluding variables like energy consumption [2] may bias results but for our defense this variables was non

significant in the model that why we were forced to remove it in the model. Future studies should extend the time series and incorporate additional controls.

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