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Abstract

This study tests the Environmental Kuznets Curve (EKC) hypothesis in Madagascar using time-series data from 1990 to 2015. Employing the autoregressive distributed lag (ARDL) approach and Granger causality tests, we analyze the nexus between CO_2 emissions, economic growth, agricultural production, and trade openness. Results confirm a U-shaped EKC, with economic growth initially reducing emissions before increasing at higher income levels. Trade openness marginally reduces emissions, while agricultural production has no significant impact. Granger causality tests indicate that economic growth drives emissions. Policy recommendations include promoting trade in environmentally friendly goods and investing in clean energy to mitigate emissions.

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 CO_2 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 (lnGDP, lnGDP^2) exhibits a U-shaped or inverted U-shaped relationship with CO_2 emissions (lnCO2), consistent with the EKC hypothesis.

2. **H2**: Agricultural production (lnAgri) influences CO_2 emissions, either positively or negatively, depending on its emission intensity.

3. **H3**: Trade openness (lnTrade) reduces CO_2 emissions by facilitating cleaner technology transfers.

4. **H4**: There exists a causal relationship between economic growth (lnGDP, lnGDP^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

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 (lnCO2), representing environmental degradation. Independent variables include the natural logarithm of real GDP (lnGDP), its square (lnGDP^2), agricultural production (lnAgri), and trade openness (lnTrade). Lagged terms (L(lnCO2, 1), L(lnGDP, 1), L(lnGDP, 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 of the work of Hussein[6], where both the dependent variable and selected regressors enter with lags to capture the dynamic adjustment process:

$$\ln(CO_2)_t = \beta_0+\beta_1 \ln(CO_2)_{t-1}+\beta_2 \ln(GDP)_t+\beta_3 \ln(GDP)_t^2 \\ +\beta_4 \ln(Agri)_t+\beta_5 \ln(Trade)_t+\beta_6 \ln(GDP)_{t-1}+\beta_7 \ln(GDP)_{t-2}+\varepsilon_t \quad (1)$$

where:

- $\ln(CO_2)_t$ is the natural logarithm of per capita carbon dioxide emissions at time t,
- $\ln(GDP)_t$ 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, *lnCO2*, *lnGDP*, *lnGDP*^{2}, and *lnTrade*—exhibit non-stationarity at level but become stationary after first differencing, thereby following an I(1) process. Specifically, their test statistics are as follows: *lnCO2* (-0.6713, p = 0.509), *lnGDP* (-0.4707, p = 0.642), *lnGDP*^{2} (-0.4511, p = 0.656), and *lnTrade* (-1.7422, p = 0.0948). In contrast, *lnAgri* is stationary in levels, as indicated by a test statistic of -2.2307 (p = 0.0357), suggesting an I(0) process at the 5% level.

Table 1: Résultats du test ADF (racine unitaire)

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

Note : * signifie significatif au seuil 5

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 *lnGDP* and its squared term (*lnGDP*^{2}) Granger-cause *lnCO2* 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 *lnCO2* to either *lnGDP* or *lnGDP*^{2}. Similarly, no significant causality is detected between *lnCO2* and either *lnAgri* or *lnTrade*, in either direction.

3.4 ARDL sstimates: 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 $lnCO2_{t-1}$ being highly significant (coefficient = 0.50, p = 0.001). Economic growth exerts a nonlinear effect on emis-

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

Null Hypothesis	F-stat.	p-value	Signif.
lnGDP → lnCO2	2.83	0.0814	*
lnCO2 → lnGDP	1.45	0.2571	
$lnGDP^2$ → lnCO2	2.88	0.0787	*
lnCO2 → $lnGDP^2$	1.42	0.2636	
lnAgri → lnCO2	1.87	0.1795	
lnCO2 → lnAgri	0.21	0.8118	
lnTrade → lnCO2	0.80	0.4614	
lnCO2 → lnTrade	2.26	0.1290	

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

sions: while *lnGDP* 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 (*lnAgri*) appears to have no statistically significant impact (p = 0.734), suggesting a negligible short-run effect. Conversely, trade openness (*lnTrade*) 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(lnCO2, 1)	0.50	[0.22 ; 0.77]	0.001***
lnGDP	-28.18	[-53.53 ; -2.82]	0.031**
L(lnGDP, 1)	-0.28	[-0.76 ; 0.20]	0.234
L(lnGDP, 2)	0.28	[-0.12 ; 0.68]	0.156
$lnGDP^2$	0.63	[0.07 ; 1.18]	0.029**
lnAgri	0.30	[-1.54 ; 2.15]	0.734
lnTrade	-0.29	[-0.63 ; 0.05]	0.090*
R^2 / 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 (χ^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

This study confirms hypothesis H1 by revealing a U-shaped Environmental Kuznets Curve (EKC) for Madagascar, where economic growth initially reduces CO_2 emissions before increasing them beyond a certain income threshold. This pattern diverges from the classical inverted U-shaped EKC posited by Grossman and Krueger [5] and the foundational insights of Kuznets [7], aligning instead with findings by Shafik and Bandyopadhyay [11] and Panayotou [8], who documented non-standard EKC trajectories in low-income countries. This evolution likely reflects a structural shift from biomass-reliant activities to less polluting sectors at early stages, followed by rising emissions driven by industrial expansion, consistent with the evidence of Selden and Song [10].

Granger causality tests offer partial support for H4, revealing a unidirectional influence running from lnGDP and $lnGDP^2$ to $lnCO_2$, while the reverse causality is not significant. Such a unidirectional dynamic corroborates Stern's [13] argument that economic growth predominantly shapes environmental outcomes in developing contexts, contrasting with the bidirectional causality found by Ben Jebli et al. [2] in OECD countries endowed with stronger environmental regulations.

The insignificant impact of agricultural production refutes H2 and stands in contrast to the negative effect reported for Somalia by Hussein et al. [6] and the positive emission effect identified by Ben Jebli et al. [2]. Madagascar's largely subsistence agriculture, characterized by minimal mechanization, likely accounts for this divergence, as noted by Selden and Song [10]. Meanwhile, the marginally negative effect of trade openness lends partial support to H3, aligning with the pollution halo hypothesis [1, 12]. Nonetheless, the weak Granger causality associated with trade openness suggests its dynamic influence on emissions remains limited, possibly due to Madagascar's export specialization in raw materials, a pattern highlighted by Cole et al. [3]. The observed persistence of emissions underscores path dependency, reinforcing Stern's [13] assertion that environmental degradation is difficult to reverse without fundamental structural changes.

Theoretically, the U-shaped EKC challenges the optimistic narrative advanced by Grossman and Krueger [5] whereby economic growth naturally improves environmental quality. Instead, it lends credence to Shafik and Bandyopadhyay [11] and Panayotou [8], who caution that low-income countries endure escalating environmental costs during early industrialization phases. The unidirectional causality from growth to emissions underscores the necessity of proactive policies to redirect this trajectory, echoing Stern's [13] prescriptions. Compared to Somalia [6], Madagascar's earlier stage of development and distinct economic structure explain the divergent EKC shape and heterogeneous effects observed.

4.1 Policy implications

Policy should prioritize trade strategies facilitating the importation of cleaner technologies [1, 12] and bolster investment in renewable energy sources to curb escalating emissions [13]. Unlike Somalia, where agriculture contributes to emission reduction [6], Madagascar's agricultural sector offers limited mitigation potential, directing focus toward industrial and energy sectors. Moreover, fiscal incentives such as tax reductions on eco-friendly goods, as suggested by Hussein et al. [6], could further enhance environmental quality.

4.2 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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