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Article

Impact of Economic Growth on Environmental Health: Evidence from Argentina, Equatorial Guinea, and South Korea

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Abstract: This study investigates the influence of economic growth on CO₂ emissions levels in three developed countries—Argentina, Equatorial Guinea, and South Korea—based on their status as high-income countries. We test the environmental Kuznets curve (EKC) hypothesis using the time series approaches to check the relationship and direction of causality among the variables over a sample spanning 1974–2020. The results show an inverted U-shaped short-run relationship in all three countries. In the long run, only South Korea supports the EKC hypothesis. Further, Granger causality results indicate the existence of causality. These long-run causal relationships between economic growth and emissions recommend one policy implication that wealthy governments must expand investments in renewable clean energy projects and R&D, with regulatory measures to suppress harmful environmental procedures and support environmentally friendly development.

Keywords: Environmental Kuznets curve; ARDL bounds testing; CO₂ emissions; economic growth; high-income

1. Introduction

The average global temperature has increased by ~0.6 °C in the last 100 years and is expected to continue rising (Baldo et al., 1998). Global warming is an outcome of human activities on the climate through large-scale consumption of fossil fuels (coal, oil, and gas) and extensive deforestation. Remarkably, the industrial revolution formed the impetus for such increased consumption. Each year, 7 billion tonnes of CO₂, chlorofluorocarbons, and methane are released into the atmosphere (Houghton, 2005). In 2018, these emissions reached an all-time high of 37.1 billion metric tonnes (Thripp, 2019). In addition, from 1900 to 2000, the global population has increased from 1.6 billion to 6.1 billion (United Nations, 2001). This ever-growing population continues to increase the demand for industries and industrial goods. As a result, industrial emissions now account for 29% of greenhouse gases (ASN Bank, 2014).

The Kuznets (1955) hypothesis postulates that environmental pollution grows faster than a firm's income level in the early economic and industrial development stages. This hypothesis is logically intuitive because individuals at this stage become more interested in income; they prioritize monetary and output goals over the environment (Dasgupta et al., 2002). During early industrialization, natural resources and hazardous pollutants were high, leading to environmental deterioration. Despite the dangers of emissions, the apathetic attitude of individuals (firms' governing bodies) toward pollution abatement was more alarming since proper disposal of hazardous substances is considered too expensive (Dinda, 2004).

Over time, environmental degradation has become a 'side effect' of a development that relies on resource (air, water, and soil) depletion, ecosystem destruction, wildlife extinction, and pollution (Johnson et al., 1997). It became crucial to encounter these negative externalities, especially in developed countries, which generate 79% of carbon emissions (Kong & Khan, 2019). Beckerman (1992), who studied the relationship between income and environment, states that being too poor to green implies that developing countries do not have the resources to protect the environment.

Only rich countries have the resources to implant green technologies to tackle environmental issues. Subsequent, a world development report during the same year noted that environmental issues caused by economic development could be resolved by more economic development. Studied the status of countries in different 'income classes' (*developing, emerging, and developed*) on the path of economic growth and level of pollution (environmental Kuznets curve or EKC) by suggesting the *sustainomics* hypothesis, which indicates a tunnel effect between the GDP per capita and resulting environmental quality at different stages of development (see Figure 1).

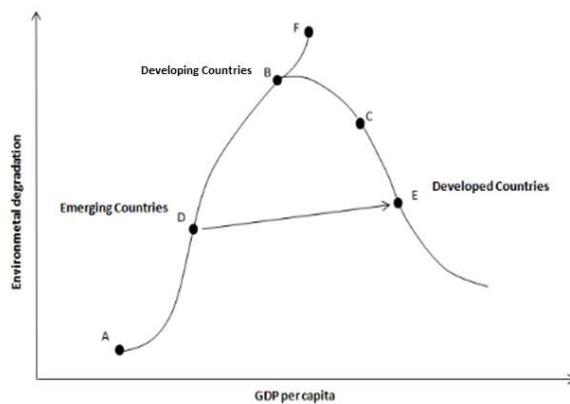


Figure 1. Tunnel Effect.

In Figure 1, point B shows the target economic growth of developing countries that can proceed to point C through sustainable development policies and clean technologies. The pathway from point B to F generates more pollutants than financial growth, so it is less likely to be followed. However, when emerging economies are given financial support and environmental-friendly technologies, they are better positioned to progress from point D to E, illustrating the tunnel effect. Thus, we see a 'grow now, clean later' attitude in high-income countries, which assumes that solutions to environmental problems can be developed at later stages of economic growth. Therefore, in a dynamic economy, improved technologies and policies that do not threaten economic growth are considered a means to recover the environment (Gill et al., 2018).

According to the *Global Environment Outlook*, the environment is changing faster, which calls for governments to save the planet since 'pollution and global warming are causing millions of more deaths than conflicts' are (United Nations, 2016). For developed countries, this is a zero-sum game: On one hand, they seek more incredible wealth, while on the other hand, they will have to spend large amounts of capital on environmental recovery, primarily due to the higher costs of pollution-abatement technologies. We thus evaluate the existence of the EKC hypothesis by taking two primary variables: CO₂ emissions and per capita GDP. Based on the above discussion, the primary purpose of this study is to examine the countries whose economic status changed from high-income to previously high-income countries such as (Equatorial Guinea), a new country entered in the high-income status (Argentina), and stable high-income (South Korea). Equatorial Guinea is a Sub-Saharan country that changed its status to a high-income country (2007–2014) 'after the discovery of huge oil reserves in 1996, with 1.7 billion bbl. and average daily oil production of 0.3 million BOPD as of December 2013' (BP, 2014) (Echendu et al., 2015). Cronin et al. (2015) report that Equatorial Guinea underwent rapid economic growth due to its oil exports, accounting for 90% of its revenues.

Argentina, the eighth-largest country globally, defaulted seven times between 1825 and 2001' (López & Nahón, 2017). However, it ultimately changed its status to a high-income country, becoming the third-largest Latin American economy. It is now a member of the G20 due to its rich

reserves of natural resources, export-based agricultural zones, well-diversified industrial sector, high-technology sector, literate population, and high Human Development Index rating.

Figure 2 illustrates the real GDP per capita of all three sample countries. South Korea's GDP is continuously rising, while Equatorial Guinea experienced a boom at the end of the nineteenth century, followed by a fall after a decade. Argentina's growth traces a zig-zag pattern over the The third sample country is South Korea. As per the International Monetary Fund, it is a highly developed country that holds the rank of the world's 11th largest economy by nominal GDP and is one of the stable members of the world's more prosperous societies. South Korea is also a member of the G20. It moved from the seventh-largest CO₂ emitter to the twelfth largest in 2018 (World Resource Institute). The governments' strategic measures to promote 'low carbon-green growth' under the National Green Growth Strategy (2009–2050) are mainly responsible for this reduction in emissions (Zhang and Choi, 2013).

chosen period. The CO₂ emissions of these countries also trace a similar pattern compared with economic growth (Figure 3): South Korea has higher emissions, the emissions of Equatorial Guinea peak when the country reaches higher per capita income, while Argentina once again follows a meandering pattern. Recent years have shown that economic study and policymaking cannot ignore the reality of the global climate crisis when assessing the benefits of any given analytical tool or policy strategy. We are now seeing widespread ecological calamities due to the failure to establish a viable global climate stabilization program. Due to companies' substantial involvement in climate change, attempts to stabilize the environment must be seen as industrial rather than macroeconomic policy. The primary objective of the climate stabilization endeavor is to significantly expand the renewable energy industry while simultaneously shutting down the global fossil fuel business (Pollin, 2021). Previous studies only analyzed the nexus between income and pollution. None of the studies have investigated how the change in the income status from high to low and vice versa has impacted their environmental health. To our knowledge, despite the importance of evaluating the level of CO₂ emissions in comparison with increasing levels of income, the literature comprises no empirical studies on individual high-income countries, especially those countries which transformed their economic status, as in this study. Thus, we critically appraise the rise in income against environmental pollutants for three developed countries from 1974 to 2020. Besides testing the EKC hypothesis, we also check for co-integration and a causal relationship between GDP growth and CO₂ emissions.

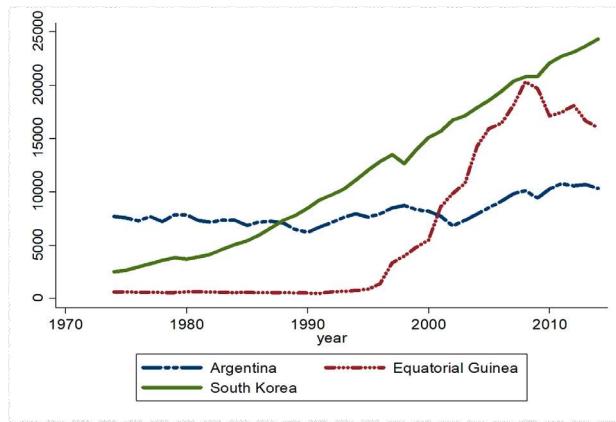


Figure 2. GDP per Capita.

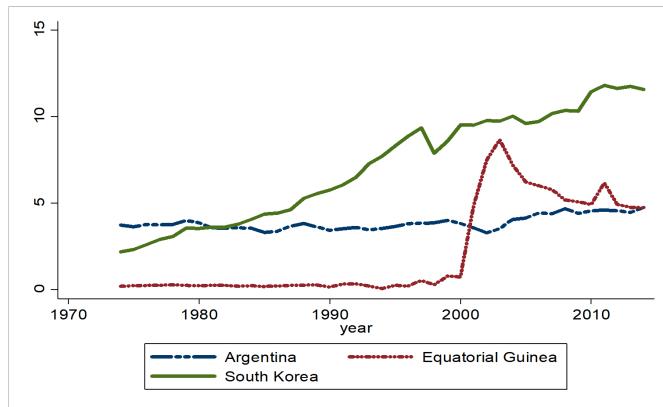


Figure 3. CO2 Emissions per Capita.

The remaining paper is organized as follows: Section 2 presents the literature survey. Section 3 encloses the data model and methodology. Section 4 reports the empirical results. Finally, section 5 presents the conclusion.

2. Literature Review

Energy consumption promotes economic growth. There is a growing body of literature on the causal relationship between economic growth and environmental deregulation. This phenomenon was first coined by Kuznets (1955), known as the *Kuznets curve*. Furthermore, Berthier et al., (2010) indicated an inverted U-shaped relationship between economic growth and income inequality. Later, Grossman and Krueger 1991 found a similar relationship between environmental conditions, economic growth, and EKC. It hypothesizes an inverted U-shaped relationship between real income and environmental pollution. That is, 'as per capita income increases, environmental pollution also increases at first and then starts declining at a turning point.' Numerous scholars and institutes have endorsed the EKC model to protect the loss of environmental health from economic activities. The World Development Report (IBRD, 1992) of the World Bank, backed by Shafik (1994), states that environmental quality is an essential element of sustainable development. Thus, numerous studies have modeled the relationship between economic growth and CO₂ emissions, one of the highest observed pollutants in environmental economics studies.

Several scholars have tested the EKC hypothesis against multiple indicators of environmental deterioration. For example, Mather et al. (1999), Koirala and Mysami (2015), Bulte and van Soest (2001), Stern et al. (1996), Ehrhardt-Martinez et al. (2002), Koop and Tole (1999), and Panayotou (1994) attribute the extensive deforestation to environmental deregulation. Moreover, sulfur dioxide (SO₂) was found to be another cause, according to the empirical findings (Brajer et al., 2008; Arouri et al., 2012; Kaufmann et al., 1998; Selden and Song, 1994; Zhoumu et al., 2015) and after all municipal waste was analyzed by (Bhattarai and Hammig, 2001; Khajuria et al., 2011; Mazzanti et al., 2006; 2009).

Most of the literature on the EKC hypothesis focuses on developed and developing countries (Cetin, 2018; Iwata et al., 2012; Liu et al., 2019; Perman and Stern, 2003; Sinha Babu and Datta, 2013). These studies neglect the policy implications of economic growth and environmental deregulation (Ang, 2008). This limitation necessitates studies that can help in sustainable development policies at the country level. As Stern et al. (1996b) believe, 'A more fruitful approach for analyzing the relationship between economic growth and environmental impact would be examining the historical experience of individual countries, using econometric and qualitative historical analyses. A comprehensive study by Zhang et al. (2021) indicated a varied influence on nations with a high GDP per capita.

Additionally, the study demonstrates that public investment in human capital and further developing green energy technologies fosters a sustainable green economy via labor-intensive and technology-oriented industrial activities, with varying consequences in various nations (Sohu et al., 2023). Taghizadeh-Hesary et al. (2021) examined the amount of investment in green projects,

particularly in the green power sector, is constrained by factors such as insufficient long-term financing, various hazards, and a poor rate of return on investment. Iqbal et al. (2021) propose many policy implications or remedies to assist governments, institutions, companies, and the general people in reducing environmental pollution through green financing. However, in a recent study, Taghizadeh-Hesary et al. (2021) found that the COVID-19 epidemic and worldwide recessions have resulted in a global decline in investments in green initiatives jeopardizing the attainment of climate-related targets. As a result, the post-COVID-19 world must transition to a green financial system by introducing new financial instruments. Green bonds—a loan instrument aimed at financing sustainable infrastructure projects—are gaining prominence in this area.

However, scholars have tested the EKC hypothesis by using time-series data for individual countries (Chen, 2012; Friedl and Getzner, 2003; Halkos and Tzeremes, 2011; Hussain et al., 2012; Lindmark, 2002; Mohapatra and Giri, 2009; Roca et al., 2001; Vollebergh et al., 2011). Decade's worth of studies have evaluated EKC hypothesis testing using distinct methodologies, and this stream of research has resulted in a rich array of perspectives. For instance, computational techniques have shifted the research focus from simple EKC testing using static ordinary least squares (OLS) models to a combination of dynamic models. EKC indicators include GDP to foreign direct investments, population density, agriculture base, electricity consumption, and trade-related proxies.

Consequently, the findings in the literature reflect immense heterogeneity, from no existence of EKC to inverted a U- or N-shaped curve (Yongsung et al., 2011). Further, Egli (2005) tested the EKC hypothesis with co-integration and the causal relationship, distinguishing the short- and long-run effects of financial growth on the concentration of environment-deteriorating elements in the atmosphere. Considering the vast literature on the EKC that uses multiple indicators, large datasets, and different econometric methodologies, we significantly contribute to this discipline by analyzing the existence of the EKC hypothesis based on economic growth and pollutant emissions in the three developed countries. In other words, when these countries' financial status changes or remains the same, what happens to their CO₂ emissions? A comprehensive study by Li et al. (2020) and Akbar et al. (2023) investigate the effect of environmental diplomacy on a country's carbon emissions. To examine whether environmental accords resulted in reductions in CO₂ emissions. The study concludes that both developed and developing nations do not adhere to treaty standards in the long term since CO₂ emissions grow as the number of treaties increases. In general, findings suggest that environmental accords are likely to waste international diplomacy that does little to address climate change. One more study by Zakari and Toplak (2021) emphasized the need for policymakers to consider non-economic and non-technological elements, such as ethics, to achieve ecologically and economically sustainable development. Furthermore, countries enact environmental legislation to safeguard the environment. According to Zakari et al. (2021), environmental accords have a considerable beneficial impact on the environment in resource-poor nations that may help them achieve sustainable development growth by 2030.

Table 1. Descriptive Statistics.

	Argentina	Equatorial Guinea	South Korea						
	CO2	GDP	GDP2	CO2	GDP	GDP2	CO2	GDP	GDP2
Mean	1.34	8.98	13.15	-0.29	7.71	17.39	1.84	9.16	16.93
Median	1.32	8.94	13.35	-1.25	6.64	17.77	2.04	9.31	17.62
Maximum	1.55	9.28	15.79	2.15	9.92	18.86	2.46	10.09	18.86
Minimum	1.19	8.73	9.09	-2.69	6.18	13.21	0.78	7.82	10.66
Std. Dev.	0.10	0.14	1.74	1.53	1.52	1.06	0.51	0.71	1.78
Skewness	0.62	0.68	-0.46	0.50	0.37	-1.78	-0.52	-0.36	-1.57
Kurtosis	2.27	2.52	2.52	1.51	1.31	7.07	1.93	1.77	5.31
Jarque–Bera	3.56	3.56	1.88	5.50	5.81	50.05	3.79	3.48	26.12
Probability	0.16	0.16	0.39	0.06	0.05	0.00	0.14	0.17	0.00

3. Data and Methodology

3.1. Data

We use annual data on per capita CO₂ emissions and per capita real GDP measured in metric tons and constant 2010 US dollars, respectively. Data on Argentina, Equatorial Guinea, and South Korea data are collected from the World Development Indicator (2021) of the World Bank, covering 1974 to 2020. The countries are selected based on data availability and current, previous, and continued high-income countries.

Carbon emissions are taken as the dependent variable to capture the nonlinear relationship between income and CO₂ emissions, with two independent variables, GDP and EKC term: the square of GDP, to predict the short-run and long-run elasticities. Table 1 reports the descriptive statistics of the sample time series in a natural logarithm.

3.2. Model and Methodology

To verify the presence of the environmental Kuznets curve in the sample countries, we follow three steps. First, we investigate the long-run relationship among the variables by employing the autoregressive distributed lag (ARDL) bounds test of co-integration. Second, we use the Granger causality test to test the causal relationship among the variables' time series. Then, the robustness analysis is conducted using fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and canonical co-integrating regression (CCR). Generally, the EKC hypothesis is specified using the following equation:

$$E = f(Y, Y^2, Z)$$

Where the dependent variable E is the environmental factor, Y is the income, and Z denotes the variables responsible for environmental deregulation. Our objective is to assess the causal relationship between economic growth and environmental stability for the sample of current, previous, and continued high-income countries. Instead of taking additional variables, we take only income and CO₂ emissions in our model. The following equation corresponds to the logarithmic form of the model:

$$\ln(E)_t = \alpha_0 + \alpha_1 \ln Y_t + \alpha_2 (\ln Y_t)^2 + \varepsilon_t \quad (1)$$

Here, each variable is in *log* (*ln*) form, where t is the time, E is the CO₂ emissions at the per-capita level, Y is the per capita real GDP, and ε is the standard error term. To validate the existence of the EKC hypothesis and confirm its significance, the signs of the two coefficients α_1 and α_2 should be positive and negative, respectively. It indicates an inverted U-shaped relationship between real income and CO₂ emissions.

There are many methods for conducting the co-integration analysis, including the residual-based approach by Engle and Granger (1987), the maximum likelihood approach by Johansen and Juselius (1990), and the fully modified OLS procedure by, and the ARDL by (Pesaran et al., 2001). We use the ARDL bounds testing approach because it has several advantages over conventional methods. For instance, the method has better reliability for small samples, has no endogeneity, and estimates long-and short-run coefficients to simultaneously capture the independent variables' effect on the dependent variable. Further, the method allows openness for integration order irrespective of whether the variables are stationary at I (0) or I(1) or a mixture of both. To capture the co-integration relationship between real income growth and CO₂ emissions through the unrestricted error correction regressions, we estimate as follows:

$$\begin{aligned} \Delta \ln \text{Co}_{2t} = & \alpha_0 + \sum_{k=1}^n \alpha_{1k} \Delta \ln \text{Co}_{2t-k} + \sum_{k=0}^n \alpha_{2k} \Delta \ln \text{GDP}_{t-k} + \sum_{k=0}^n \alpha_{3k} \Delta (\ln \text{GDP}_{t-k})^2 + \\ & \Delta_1 \text{Co}_2 \ln \text{Co}_{2t-1} + \Delta_2 \text{Co}_2 \ln \text{GDP}_{t-1} + \Delta_3 \text{Co}_2 \ln (\text{GDP}_{t-1})^2 + \varepsilon_{1t} \end{aligned} \quad (2)$$

$$\Delta \ln \text{GDP}_t = \beta_0 + \sum_{k=1}^n \beta_{1k} \Delta \ln \text{GDP}_{t-k} + \sum_{k=0}^n \beta_{2k} \Delta \ln \text{Co}_{2t} + \sum_{k=0}^n \beta_{3k} \Delta (\ln \text{GDP}_{t-k})^2 + \Delta_1 \text{GDP} \ln \text{Co}_{2t-1} + \Delta_2 \text{GDP} \ln \text{GDP}_{t-1} + \Delta_3 \text{GDP} \ln (\text{GDP}_{t-1})^2 + \varepsilon_{2t} \quad (3)$$

$$\Delta (\ln \text{GDP}_t)^2 = \theta_0 + \sum_{k=1}^n \theta_{1k} \Delta (\ln \text{GDP}_{t-k})^2 + \sum_{k=0}^n \theta_{2k} \Delta \ln \text{GDP}_{t-k} + \sum_{k=0}^n \theta_{3k} \Delta \ln \text{Co}_{2t-k} + \Delta_1 \text{GDP}^2 \ln \text{Co}_{2t-1} + \Delta_2 \text{GDP}^2 \ln \text{GDP}_{t-1} + \Delta_3 \text{GDP}^2 \ln (\text{GDP}_{t-1})^2 + \varepsilon_{3t} \quad (4)$$

In equation (2), α_0 is the drift element and ε_{1t} is the error term. Further, α_1 , α_2 , and α_3 are the error correction dynamics, whereas δ_{1co_2} , δ_{2co_2} , and δ_{3co_2} are the long-run association and the same pattern are applied to equations (3) and (4). In equation (2), following the first step of the ARDL approach, we test the presence of the long-run co-integrating relationship using the null hypothesis— $H_0: \delta_{1co_2} = \delta_{2co_2} = \delta_{3co_2} = 0$ —against the alternative hypothesis $H_0: \delta_{1co_2} \neq \delta_{2co_2} \neq \delta_{3co_2} \neq 0$ —examined through the F statistics. We apply the same process to equations (3) and (4).

Next, we determine the long-run co-integrating relationship among the variables by comparing the calculated F statistics with two sets of critical values found in the literature (Pesaran et al., 2001b). The first set comprises the lower critical bound (LCB) values for I(0) variables, while the second set holds the upper critical bound values (UCB) for I(1) variables. The null hypothesis of 'no co-integration' will be rejected if the calculated F statistics value is higher than the UCB value, but the hypothesis cannot be rejected if the calculated F statistics value is smaller than the LCB value. The value between the two limits, UCB and LCB, will be inconclusive when the long-run association among the variable series is confirmed with a negative and significant value of the error correction term (ECT). Moreover, to run the ARDL model, the order of lags is based on the Schwartz Bayesian criteria (SBC) and Akaike's information criteria (AIC), which select the smallest possible and maximum relevant lag lengths, respectively. Once the existence of a long-run relationship has been confirmed, we estimate the error correction model (ECM) and Karagozoglu and Lindell (2000) as follows:

$$\Delta \ln \text{Co}_{2t} = \alpha_0 + \sum_{k=1}^n \alpha_{1k} \Delta \ln \text{Co}_{2t-k} + \sum_{k=1}^n \alpha_{2k} \Delta \ln \text{GDP}_{t-k} + \sum_{k=1}^n \alpha_{3k} \Delta (\ln \text{GDP}_{t-k})^2 + \theta ECT_{t-1} + \varepsilon_{1t} \quad (5)$$

$$\Delta \ln \text{GDP}_t = \beta_0 + \sum_{k=1}^n \beta_{1k} \Delta \ln \text{GDP}_{t-k} + \sum_{k=1}^n \beta_{2k} \Delta \ln \text{Co}_{2t} + \sum_{k=1}^n \beta_{3k} \Delta (\ln \text{GDP}_{t-k})^2 + \theta ECT_{t-1} + \varepsilon_{2t} \quad (6)$$

$$\Delta (\ln \text{GDP}_t)^2 = \theta_0 + \sum_{k=1}^n \theta_{1k} \Delta (\ln \text{GDP}_{t-k})^2 + \sum_{k=1}^n \theta_{2k} \Delta \ln \text{GDP}_{t-k} + \sum_{k=1}^n \theta_{3k} \Delta \ln \text{Co}_{2t-k} + \theta ECT_{t-1} + \varepsilon_{3t} \quad (7)$$

The ECT_{t-1} equations (5) to (7) indicate the speed of adjustment, that is, the time taken to restore the long-run equilibrium. Diagnostic tests such as functional form, serial correlation, normality, and heteroscedasticity tests are conducted to ensure the model's fitness. Further, as per (Pesaran et al., 2001b), the long- and short-run stability coefficients are checked using the *cumulative sum* and *cumulative sum square* tests. These tests confirm the model's stability if the test statistics value lies within the plot of two straight lines representing critical bounds at the 5% significance level. Note that the ARDL method only confirms the presence or non-existence of co-integration among variables series, so we employ the (Granger 1969) test to verify the existence and direction of causality. The enlarged version of the Granger causality test with the ECM encompassing the vector error correction model (VECM) and multivariate n^{th} order is formulated as follows:

$$(1 - B) \begin{bmatrix} \ln\text{Co}_{2t} \\ \ln\text{GDP}_t \\ \ln\text{GDP}_t^2 \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \sum_{i=1}^P (1 - B) \begin{bmatrix} d_{11,i} d_{12,i} d_{13,i} \\ d_{21,i} d_{22,i} d_{23,i} \\ d_{31,i} d_{32,i} d_{33,i} \end{bmatrix} \begin{bmatrix} \ln\text{Co}_{2t-i} \\ \ln\text{GDP}_{t-i} \\ \ln\text{GDP}_{t-i}^2 \end{bmatrix} + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \end{bmatrix} [ECT_{t-1}] + \begin{bmatrix} \gamma_{1t} \\ \gamma_{2t} \\ \gamma_{3t} \end{bmatrix}$$

Where $(1 - B)$ is the lag operator, d denotes the parameters of estimation, γ_t denotes the zero mean uncorrelated random disturbance terms, and ECT_{t-1} is the lagged error term. The VECM determines the direction of the causality, while the significance value of the lagged ECT, ECT_s , verifies the long-run causal relationship among the variable series. In addition, the short-run Granger causal relationship can be detected through the significant F statistics value of the lagged independent variables.

4. Empirical Results

4.1. Unit-Root Tests

Before the ARDL model, we employ three-unit root tests—augmented Dickey-Fuller, Phillips-Person, and Lee-Strazicich tests—to confirm the required $I(0)$ or $I(1)$ integration order of variables series. Because of the substantial likelihood, the sample data contain structural breaks, thus avoiding the spurious results of traditional stationarity tests. The Lee-Strazicich test is used if a structural break(s) occur(s) in the data, where the augmented Dickey-Fuller (1979) and PHILLIPS- PERRON (1988) tests would generate misleading and biased results (Phillips & Perron, 1988).

The existence of a single structural break that further extends to two and five breaks was proposed by Zivot and Andrews (1992), Lumsdaine and Papell (1997), and Kapetanios (2005), respectively. However, these tests bear a linearity assumption limitation under the null hypothesis.

Therefore, if there is a break under the null hypothesis, we will observe size distortions that will lead us to reject the null hypothesis as these results are erroneously estimated breakpoints (ALTINAY, 2005). Lee and Strazicich (2004) developed their test to overcome the assumption that breaks are accommodated under null and alternative hypotheses. Table 2 reports the empirical findings of the unit root tests, starting with the augmented Dickey-Fuller and Phillips-Person tests, followed by the Lee-Strazicich tests with single and double structural breaks. In structural breaks in the time series, we find three series: CO₂ emissions of Argentina and South Korea and the GDP of Equatorial Guinea are stationary at the first difference, while the remaining series are stationary at level.

Table 2. Augmented Dickey-Fuller, Phillips-Person, and Lee and Strazicich (2004) with single and double structural breaks.

Variable	ADF test	PP test	Lee-Strazicich test (One Break)	Lee-Strazicich test (Two Breaks)
t-Statistic	I(•)	I(•)	t-Statistic	TB1 I(•) t-Statistic TB1 TB2 I(•)

Argentina									
CO2	-4.80***	I(1)	-9.32***	I(1)	-4.57** (4)	1993 I(0)	-10.16*** (1)	20072010I(1)	
GDP	-5.26***	I(1)	-5.17***	I(1)	-6.32*** (7)	1987 I(0)	-6.23** (7)	19892000I(0)	
GDP2	-6.56***	I(1)	-13.37***	I(1)	5.90*** (1)	1995 I(0)	-7.71*** (1)	19911995I(0)	
Equatorial Guinea									
CO2	-7.78***	I(1)	-7.65***	I(1)	-5.34*** (7)	1998 I(0)	-6.21** (7)	19911999I(0)	
GDP	-3.50**	I(1)	-3.48**	I(1)	-5.76*** (7)	1995 I(0)	-10.16*** (1)	20072010I(1)	
GDP2	-6.56***	I(1)	-13.3***	I(1)	-4.92*** (7)	1994 I(0)	-7.71*** (1)	19911995I(0)	
South Korea									
CO2	-6.51***	I(1)	-6.62***	I(1)	-4.84** (4)	2001 I(0)	-7.46*** (4)	19962002I(1)	
GDP	-4.56***	I(1)	-5.80***	I(1)	-6.37*** (7)	1998 I(0)	-5.84* (5)	19912003I(0)	
GDP2	-6.39***	I(1)	-6.42***	I(1)	-4.25* (8)	1997 I(1)	-6.65** (7)	19922004I(0)	

Notes. The numbers in parentheses are *t* statistics. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.

We find that every variable series of each country is non-stationary at the level under the former two tests; when transformed to the first difference, each series rejects the null hypothesis at the 1% significance level. On the other hand, Lee and Strazicich (2004) demonstrated a different integration order; except for South Korea's GDP square, the remaining series of the three countries are stationary at the level for single the break hypothesis. Finally, for more robust testing, we find three series for two structural breaks in the time series: CO2 emissions of Argentina and South Korea and the GDP of Equatorial Guinea are stationary at the first difference, while the remaining series are stationary at level.

4.2. Cointegration

In the next step, we use the most widely used co-integration measure, ARDL bounds testing, developed (Pesaran et al., 2001b) to capture the long-run equilibrium among the variable series. Bounds testing is advantageous compared with other conventional co-integration techniques for three reasons. First, it can be applied to both a mixed I(0) or I(1) integration order. Second, it performs well with a small or finite sample size(Narayan, 2005). Third, it is a bias-free technique for long-run estimations (Harris and Sollis, 2003). The decision regarding co-integration is based on an F statistics comparison with the UC Band LCB values. The UCB considers all variables at I(1) integration order, while LCB takes level order I(0) for all variables (Pesaran et al., 2001). Therefore, a weaker UCB value than the computed F-statistics would validate co-integration among variables. Therefore, the decision is reserved when the F statistics value is below the LCB value. However, the decision on co-integration presence will be inconclusive if the computed value of the F statistics is less than the UCB value and more than the LCB value. In this case, the lagged ECT decides the long-term relationship. The results in Table 3 present the F statistics of three countries based on the null hypothesis— $H_0: 1=2=3=0$ —against the alternative hypothesis— $H_1: 1 \neq 2 \neq 3 \neq 0$, denoting CO2 emissions as the dependent variable, while the GDP and GDP square are the independent variables.

Table 3. The Results of Co-integration.

Country	Argentina	Equatorial Guinea	South Korea
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<i>F</i> statistics	9.225***	11.463***	9.250***
Significance level	1%	5%	10%
I (0)	5.15	3.79	3.17
I (1)	6.36	4.85	4.14

Note. The numbers in parentheses are *t* statistics. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.

The *F* statistics values for Argentina, Equatorial Guinea, and South Korea are 9.225, 11.463, and 9.250, respectively, which are much higher than the UCB values to reject the null hypothesis at the 1% significance level. Such a rejection implies that the CO₂ emissions, GDP, and GDP square series are mutually co-integrated in Argentina, Equatorial Guinea, and South Korea. After verifying co-integration in the time series, we conduct the causality test by deriving the marginal impact of GDP and GDP square on the CO₂ emissions for the long-and short-run elasticities. That allows us to confirm the existence of the EKC for the sample countries.

As shown in Table 4, the per capita GDP positively and statistically significantly impacts CO₂ emissions. Specifically, a 1% permanent increase in GDP raises CO₂ emissions in the long run by 0.60% and 0.96% in Argentina and Equatorial Guinea, respectively. The same pattern continues for GDP square: A 1% increase in GDP square significantly boosts the CO₂ emissions by 0.01% and 0.28% in that order for both countries. For South Korea, the significant positive and negative long-run elasticities are 0.67% and -0.02% for GDP and GDP square, respectively, which aligns with our expectations. That confirms the existence of EKC in South Korea. We now proceed to short-run results and diagnostic tests (Table 5). The short-run elasticities for each of the three countries are computed using the ECM from equations (5) to (7). The results show a positive and significant relationship between Argentina's economic growth and CO₂ emissions.

Table 4. ARDL long run estimation results.

Variable	New High Income			Old High Income			Stable High Income		
	Argentina			Equatorial Guinea			South Korea		
	ARDL (2,0,1) based on SBICARDL (3,4,2) based on AICARDL (1,0,3) based on SBIC								
Variable	Coefficient	SE	<i>t</i> stat	Coefficient	SE	<i>t</i> stat	Coefficient	SE	<i>t</i> stat
Δ GDP	0.42***	0.08	5.07	1.66***	0.47	3.53	0.39***	0.07	5.24
Δ GDP (-1)				-0.71	0.44	-1.59			
Δ GDP (-2)				-0.46	0.45	-1.02			
Δ GDP (-3)				-0.94*	0.49	-1.93			
Δ GDP2	-0.00	0.00	-0.31	-0.60***	0.16	-3.75	-0.00	0.01	-0.01
Δ GDP2 (-1)				-0.22	0.14	-1.53	0.00	0.01	0.40
Δ GDP2 (-2)							-0.02***	0.01	-2.89
ECT	-0.70***	-0.14	5.01	-1.18***	0.20	-5.84	-0.59***	0.10	-5.43

Note. The numbers in parentheses are *t* statistics. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.

Their coefficient of the GDP square is less than zero and insignificant; hence, the results do not support the EKC hypothesis in the short run. For Equatorial Guinea, we find a significant and positive relationship between GDP growth and CO₂ emissions but a negative and significant coefficient of GDP square. That indicates the existence of the EKC in the short run at the 1% significance level. Finally, after validating an inverted U-shaped curve between GDP growth and CO₂ emissions in the long run, we confirm the short-run existence of the EKC for South Korea for GDP and at a two-time lag of the GDP square.

Table 5. ARDL short-run estimation results.

Variable	Argentina		Equatorial Guinea		South Korea	
	ARDL (2,0,1) SBIC		ARDL (3,4,2) AIC		ARDL (2,0,4) SBIC	
	Coefficient	SE	<i>t</i> -statistic	Coefficient	SE	<i>t</i> -statistic

GDP	0.60***	0.06	9.26	0.96***	0.03	27.43	0.67***	0.01	43.14
GDP 2	0.01*	0.00	1.87	0.28***	0.06	4.23	-0.02***	0.00	4.09
C	-2.99***	0.61	-4.90	15.02***	2.80	5.36	-3.89***	0.19	-19.85

Note. The numbers in parentheses are t statistics. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.

The stability of the ECM coefficients and the long-run goodness of fit for the model are further confirmed with the cumulative sum and cumulative sum square. The two ECMs for the three countries are illustrated in Figures 4–9: All remain within the critical bounds at the 5% significance level.

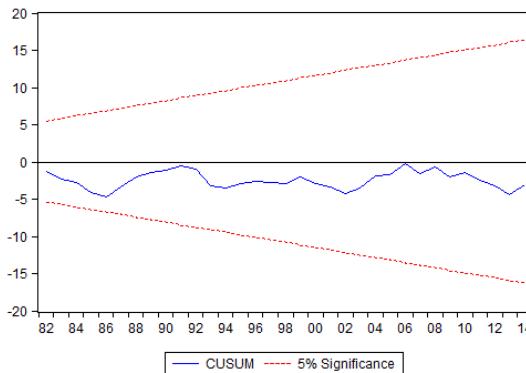


Figure 4. Argentina cumulative sum graph.

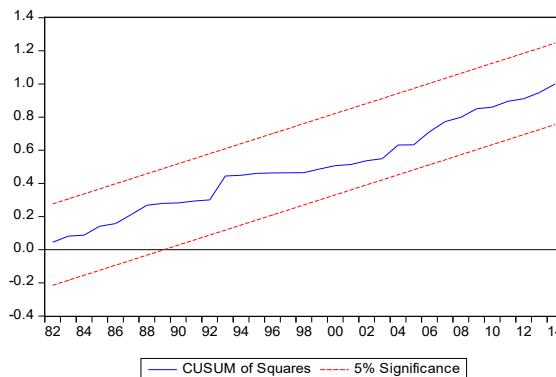


Figure 5. Argentina cumulative sum square graph.

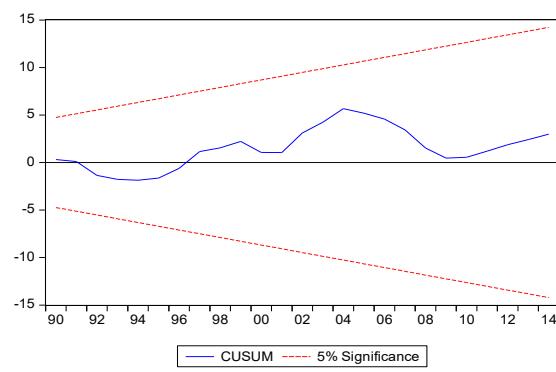


Figure 6. Equatorial Guinea cumulative sum graph.

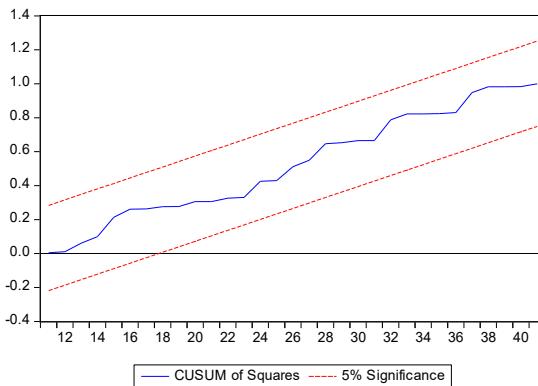


Figure 7. Equatorial Guinea cumulative sum square graph.

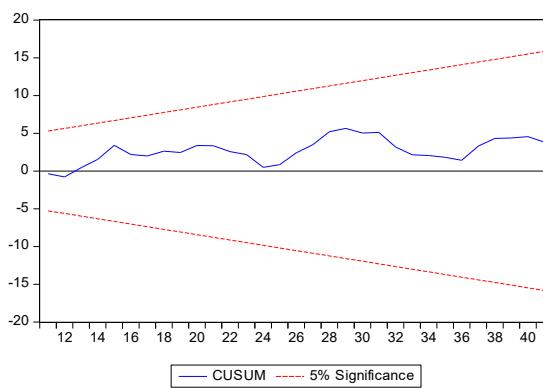


Figure 8. South Korea cumulative sum graph.

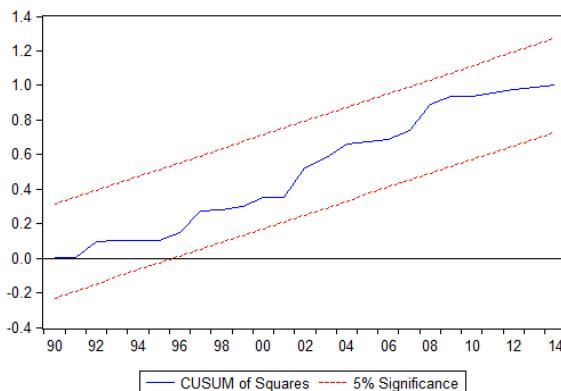


Figure 9. South Korea cumulative sum square graph.

After yielding successful results on the cointegrated causal relationship between CO₂ emissions and economic growth, we employ the VECM Granger causality test to identify the direction of the relationship among the time series. Table 6 reports the results of the Granger causality test, indicating a significant long-run relationship for all three countries. However, Argentina shows a bidirectional long-run significant relationship between GDP and CO₂ emissions.

In the short run, findings from Argentina reveal a unidirectional negative causal relationship that runs from GDP square to CO₂ emissions. We observe several short-run Granger causalities for Equatorial Guinea; the results reveal a unidirectional positive and significant short-run relationship from GDP to CO₂ emissions. The only bidirectional and significant relationship between GDP square and CO₂ emissions exists at the 5% level. Finally, the results for South Korea indicate a unidirectional short-run negative causality from economic growth to CO₂ emissions.

Table 6. Granger Causality Results.

Argentina			Equatorial Guinea						South Korea					
			Granger Causality F-statistics											
Short-run	Long run		Short-run	Long run		Short-run	Long run		Short-run	Long run		Short-run	Long run	
Δ	Δ	Δ	ECT _{t-1}	Δ	Δ	Δ	ECT _{t-1}	Δ	Δ	Δ	Δ	ECT _{t-1}		
CO2	GDP	GDP2	(tstats)	CO2	GDP	GDP2	(tstats)	CO2	GDP	GDP2	(tstats)			
0.18	-13.57*	-0.81***		0.14**	0.71***	-1.27***		-0.22*	-2.60	-0.84***				
Δ CO2	(0.54)	(-1.74)	(-3.10)		(2.19)	(2.88)	(-6.33)		(-1.78)	(-0.67)	(-5.64)			
Δ GDP	-0.00	7.26	0.02	-0.26	0.45	-0.13*	-0.15	-4.06	-0.37***					
	(-0.02)	(0.208)	(0.05)	(-0.64)	(0.73)	(-1.67)	(-0.54)	(-0.64)	(-3.44)					
	0.01	0.01	13.08	-0.33**	-0.06	0.041	0.01	-0.00	-3.18					
Δ GDP2	(0.93)	(0.77)	(1.58)	(-2.29)	(-1.05)	(0.89)	(0.92)	(-0.13)	(-0.98)					

Note. The numbers in parentheses are *t* statistics. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.

Table 7 reports the results of the FMOLS, DOLS, and CCR estimators to check the robustness of the model. The robustness of the long-run findings of the ARDL estimations for the three countries is fully validated. The results confirm the absence of the EKC in the long run for Argentina and Equatorial Guinea but a presence for South Korea.

Table 7. Co-integration Regression Results.

Variable	FMOLS estimates			DOLS estimates			CCR estimates		
	Argentina	Coef.	<i>p</i> -value	Coef.	<i>p</i> -value	Coef.	<i>p</i> -value	Coef.	<i>p</i> -value
GDP		0.605***	0.000	0.572***	0.000	0.600***	0.000		
GDP2		0.007	0.112	0.009	0.204	0.008	0.117		
Equatorial Guinea									
GDP		0.942***	0.000	0.927***	0.000	0.941***	0.000		
GDP2		0.268***	0.000	0.399***	0.000	0.260***	0.000		
South Korea									
GDP		0.696***	0.000	0.663***	0.000	0.697***	0.000		
GDP2		-0.023***	0.000	-0.026***	0.000	-0.023***	0.000		

5. Conclusions

We explored the EKC hypothesis's existence, including causal and long-run relationships between CO₂ emissions and economic growth per capita for Argentina, Equatorial Guinea, and South Korea. The period covers 1974 to 2020, and we used the ARDL method proposed by (Pesaran et al. (2001a) and the FMOLS, DOLS, CCR, causality, and stability tests. We found that all three countries exhibit a robust long-run relationship between CO₂ emissions and per capita GDP. An inverted U-shaped curve exists only in the short run for Equatorial Guinea and South Korea. In the long run, only South Korea exhibits the EKC. The FMOLS, DOLS, and CCR estimations confirm the long-run findings of the ARDL approach, which confirms the robustness of the results. The VECM Granger causality test checked the variables' linkage and direction of causality. It specified a significant long-run relationship from GDP to CO₂ emission for each country; except for Argentina, the remaining two countries exhibit a bidirectional long-run significant relationship. This result proves that the decoupling of the two variables is unlikely under the economic policy structure of the sample countries.

In the short run, Argentina has a similar unidirectional negative relationship that runs from GDP square to CO₂ emissions, whereas South Korea exhibits a unidirectional negative causality from GDP to CO₂ emissions. Equatorial Guinea exhibits more causal associations following the long-run path: a significant and negative unidirectional positive relationship from GDP to CO₂ emissions and the only bidirectional and significant negative relationship between GDP square and CO₂ emissions.

Conclusively, in the short run, Argentina's GDP square has a negative impact on CO₂ emissions. For South Korea, economic growth has a negative impact on CO₂ emissions. Finally, for Equatorial

Guinea, the GDP has only a positive impact, while the GDP square has a positive and negative impact on CO₂ emissions. It implies that in the short run, after the turning point on the EKC curve, an increase in the GDP causes a decline in CO₂ emissions in Argentina. In the long run, the unidirectional causality from GDP to CO₂ emissions indicates that the Argentinian government must invest more in pollution abatement policies to encourage sustainable development. Pollution reduction strategies such as emissions tax, carbon credit policy, enhanced use of clean energy technologies, and energy efficiency schemes will not harm the long-term economic growth of this newly high-income country but cement its economic status along with better environmental conditions.

In Equatorial Guinea, a former high-income country that once experienced the oil boom, a short-run, bidirectional, positive, and negative relationship runs from GDP square to CO₂ emissions. Thus, the rise and fall in the GDP square align with the economic growth. That is, the EKC hypothesis in the short run is confirmed. Thus, Equatorial Guinea must employ environmentally friendly measures and stringent environmental laws without adversely affecting GDP growth. In South Korea, an increase in GDP does not increase the pollution level in the short run, which is a rare case that might be attributed to the country's 'low carbon green growth' policy (see section 1) and five-year plan for green growth (2009–2013). These short-run causality results for South Korea are in line with Sonnenschein and Mundaca (2016), who revealed a short-term (2008–2012) enhancing effect of GDP per capita on CO₂ emissions with lower emissions. However, the 1971–2012 period is evidence of worsening CO₂ intensity during the early years of the Green Growth Strategy. Therefore, South Korea still requires a more robust low-carbon growth policy that matches its economic growth. It must discard fossil fuels subsidies and increase energy efficiency rather than offer 'green growth engines.' In addition, it must implement pricing reforms, carbon energy taxes, and a strict regulatory system. Without good sustainable development policies, stable financial growth in South Korea is impossible without environmental deterioration.

Future researchers may broaden this study to more high-income countries by using large and improved datasets. That would allow an analysis of these countries before and after becoming high-income countries. It would also refine findings to understand long-term policy implications, thus ensuring continuous environmentally sustainable growth.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript.", please turn to the [CRediT taxonomy](#) for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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