# Environmental Degradation and Economic Performance in Botswana: A Test of the Environmental Kuznets Curve, Pollution Haven and Pollution Halo Hypotheses

**RESEARCH ARTICLE**

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*This article is part of a special issue titled Bridging Power and Knowledge: Addressing Global Imbalances in Knowledge Systems for Sustainable Futures.*

# PLAIN-LANGUAGE SUMMARY

### Economic Growth vs Environment

Botswana's economy relies heavily on diamond mining, contributing approximately 30% of GDP and over 80% of export earnings, which drives economic growth but creates environmental challenges including deforestation, water contamination, and air pollution.

### U-Shaped Relationship

The study finds that initially, economic growth reduces $CO_2$ emissions, but as the economy develops further, emissions begin to increase, creating a U-shaped pattern.

### Foreign Investment Impact

Foreign investment shows mixed effects - it initially increases pollution (Pollution Haven effect) but eventually brings cleaner technologies (Pollution Halo effect).

### Policy Recommendations

The study recommends investing in green technologies, strengthening environmental regulations, and promoting sustainable practices to balance economic growth with environmental protection.

# ABSTRACT

This study explores the relationship between economic growth and environmental degradation in Botswana, a relatively understudied Southern African economy, by examining the Environmental Kuznets Curve (EKC), Pollution Haven Hypothesis (PHH), and Pollution Halo Hypothesis (PHLH). Using the Autoregressive Distributed Lag (ARDL) model–which allows for mixed integration orders and is suitable for small sample sizes–on data from 1991 to 2019, the study finds a U-shaped EKC, with a turning point at a GDP per capita of $3,479.38. Botswana, with a mean GDP per capita of approximately $5,500 and a 2019 value around $6,485, sees increased emissions. Short-term evidence supports the PHH, while long-term evidence supports the PHLH. This indicates that Botswana's current economic trajectory may be environmentally unsustainable without policy shifts. The study recommends investing in green technologies, strengthening environmental regulations, and promoting sustainable practices to mitigate the environmental impact of economic growth.


**Keywords:** Environmental Kuznets Curve, Pollution Haven Hypothesis, Pollution Halo Hypothesis, Environmental Degradation, Botswana.

# INTRODUCTION

Environmental degradation poses serious risks to global human well-being and economic stability (Nguyen et al., 2023; Bibi & Jamil, 2021; Sarkodie, 2018; World Bank, 2012). Climate change–evident through rising sea levels, floods, and droughts–intensifies social challenges such as migration and urbanization (Wang et al., 2020). Global carbon dioxide ($CO_2$) emissions have surged from 2 billion tons in 1900 to over 34 billion tons today, with projections indicating a potential doubling or tripling by 2050 (United Nations Climate Change, 2023). In response, international agreements like the Paris Agreement and Kyoto Protocol have set targets to reduce emissions and support climate action in developing nations (United Nations Climate Change, 2023).

In Botswana, these global challenges are mirrored by rising temperatures, increasing water scarcity, and growing vulnerability to climate shocks as illustrated in Figure 1. Addressing environmental degradation is thus central to achieving the country's development goals and international commitments, including Vision 2036 and the Sustainable Development Goals (SDGs).

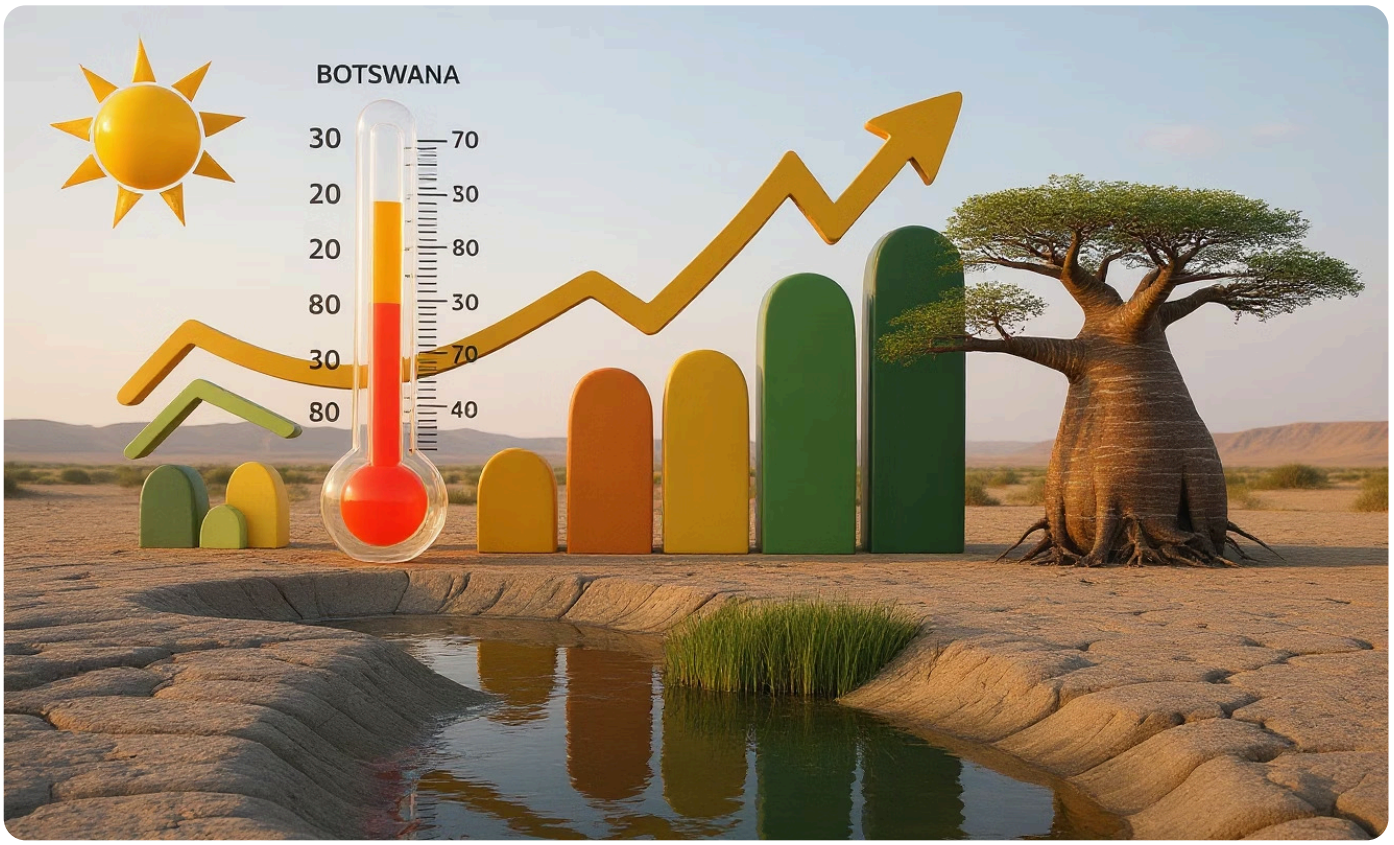



*Figure 1: Botswana's environmental challenges*

The Southern African region faces distinct environmental vulnerabilities, including rising temperatures and increased frequency of extreme climate events (Nhamo et al., 2018). These developments threaten water security, agricultural output, and broader socio-economic development, disproportionately affecting populations dependent on subsistence farming (Food and Agriculture Organization [FAO], 2021; United Nations Development Programme [UNDP], 2023). In response, the Southern African Development Community (SADC) (2018) has promoted regional strategies such as the establishment of Transfrontier Conservation Areas (TFCAs) to safeguard ecosystems and enhance regional integration.

However, addressing environmental degradation remains deeply entangled in broader power dynamics. Global environmental frameworks, such as the Paris Agreement, often impose conditionalities on aid or climate finance, influencing domestic environmental policies in countries like Botswana. Similarly, foreign direct investment (FDI) decisions and investor-state dispute mechanisms may shape national regulatory space, leading to regulatory chill in environmental governance (Bouzahzah, 2022).

In the context of Botswana–where economic growth is driven by natural resource extraction, tourism, and agriculture–this study critically examines the relevance of mainstream environmental economic theories such as the Environmental Kuznets Curve (EKC), Pollution Haven Hypothesis (PHH), and Pollution Halo Hypothesis (PHLH) (Bibi & Jamil, 2021; Bouzahzah, 2022). The mining sector, accounting for approximately 30% of GDP and over 80% of export earnings, significantly contributes to environmental degradation through deforestation, water contamination, and air pollution (Juana, 2014; Madebwe et al., 2021) (see Figure 2).

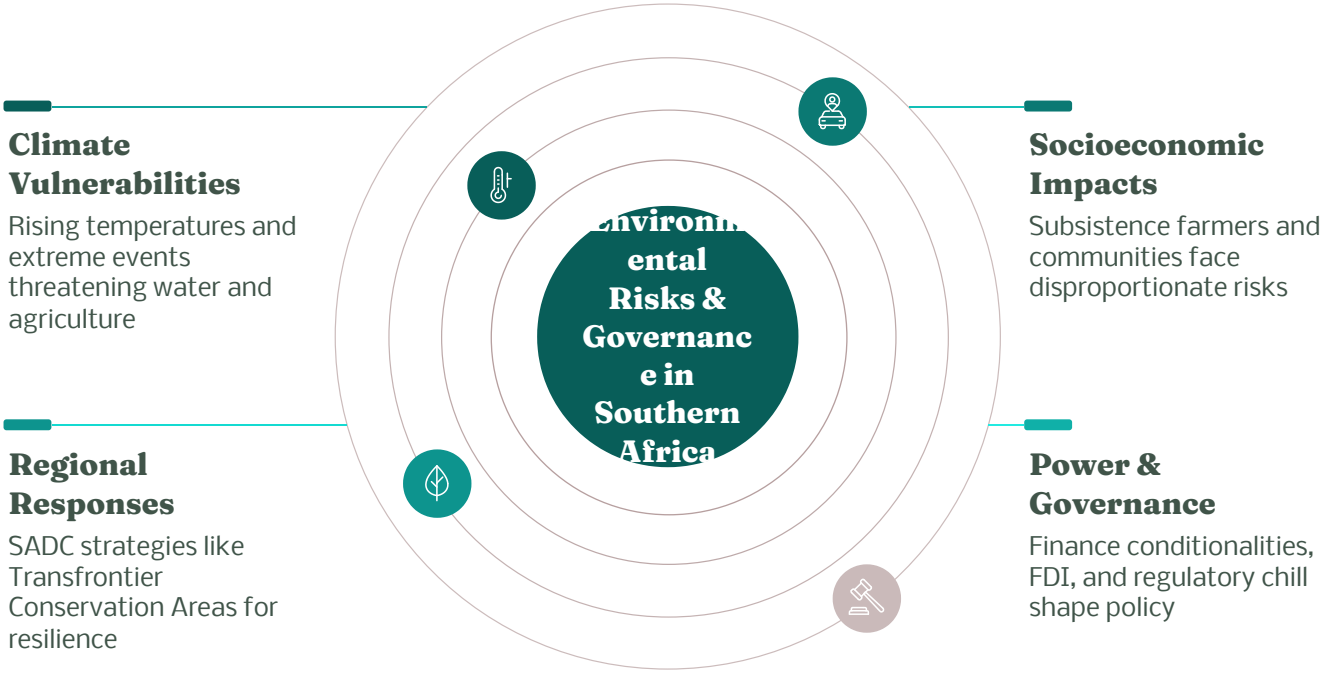



*Figure 2: Environmental risks and governance dynamics in Southern Africa*

## Environmental sustainability issues in Botswana

Balancing economic growth with environmental sustainability is a formidable challenge faced by countries striving for development (Udeagha & Ngepah, 2023). Botswana, a landlocked country in Southern Africa, epitomises this struggle as it grapples with the consequences of rapid economic growth driven by its abundant natural resources and burgeoning industries (Hambira etal., 2020). While economic progress has brought about improvements in living standards and infrastructure, it has also placed pressure on natural ecosystems and increased vulnerability to climate risks, underscoring the need for sustainable and inclusive growth strategies (United Nations Development Programme, 2023).

At the heart of Botswana's economic success lies its mining industry, particularly the extraction of diamonds, which has propelled the country into one of Africa's leading economies (Juana, 2014). However, this economic boon has come at a significant environmental cost. Diamond mining operations, characterised by extensive land excavation and water usage, have led to deforestation, soil erosion, and water pollution (Madebwe et al., 2021; Juana, 2014).

### Mining Industry Impact

- Approximately 30% of GDP and over 80% of export earnings contribution
- Extensive land excavation
- Water contamination
- Deforestation and soil erosion

### Tourism Challenges

- Habitat encroachment
- Poaching threats
- Resource depletion
- Climate change vulnerability

### Agricultural Vulnerabilities

- Climate-induced droughts
- Erratic rainfall patterns
- Land degradation
- Food security risks

Botswana's rich biodiversity, including iconic species such as elephants, lions, and rhinos, has made it a prime destination for ecotourism (Gumbo, 2022). The Okavango Delta, a UNESCO World Heritage Site and the largest inland delta in the world, teems with wildlife and supports diverse ecosystems (Gumbo, 2022; SADC, 2018). However, the burgeoning tourism industry, while providing economic opportunities, poses challenges to biodiversity conservation.

Agriculture remains a cornerstone of Botswana's economy, providing livelihoods for a significant portion of the population (UNDP, 2023). However, climate change-induced droughts, erratic rainfall, and land degradation pose formidable challenges to agricultural productivity and food security (Mogotsi, 2022; Temoso et al., 2018).

## Economic growth, trade, foreign direct investments, and the environment

Climate stress and environmental degradation represent global challenges stemming from socio-economic activities, manifesting in phenomena like floods, droughts, wildfires, rising sea levels, and pollution (Heshmati, 2021). The World Economic Forum (WEC) reports a significant increase in $CO_2$ emissions, with projections indicating a potential doubling or tripling by 2050 (WEC, 2022).

The correlation between environmental pollutants and economic growth is a topic of interest, as economic development often comes at the expense of environmental quality. The EKC hypothesis posits that environmental degradation initially rises with economic growth but eventually declines as economies mature (Bibi & Jamil, 2021). International trade and foreign direct investment (FDI) are crucial drivers of economic growth but can also impact environmental outcomes (see Figure 3).

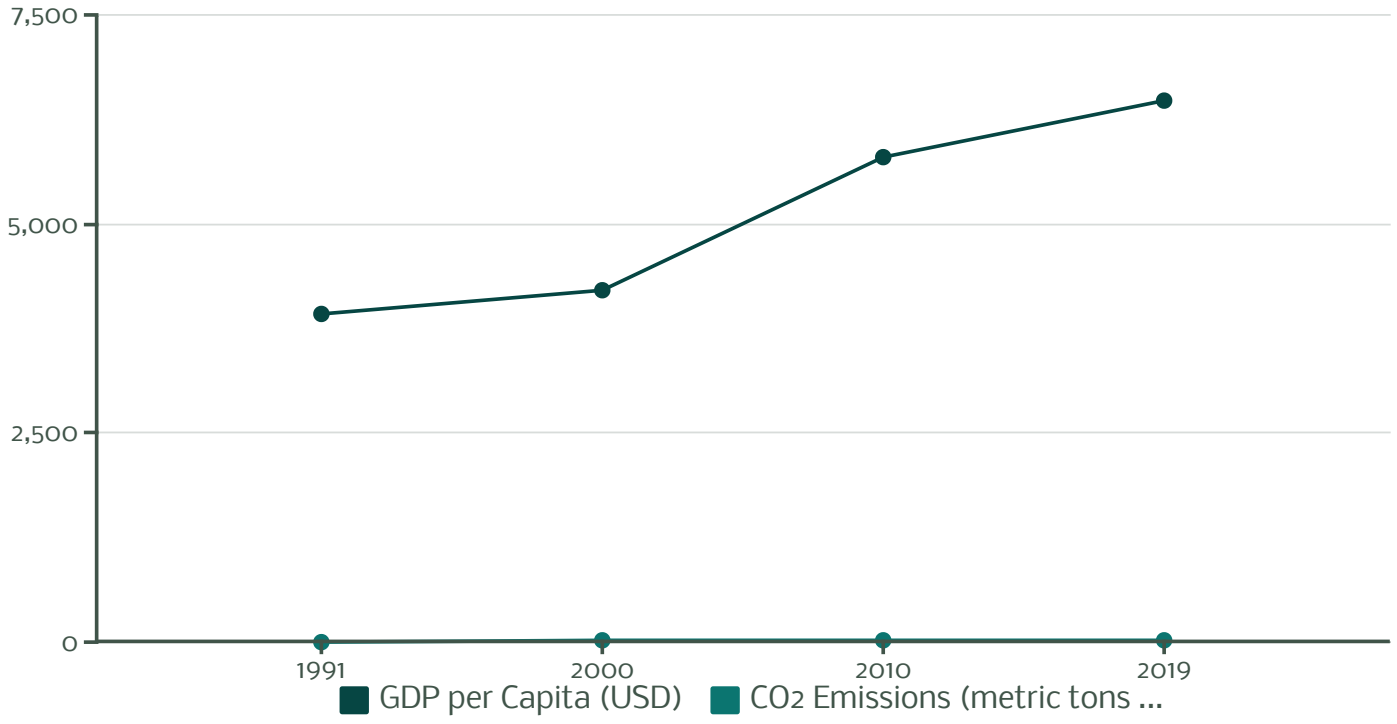



*Figure 3: Botswana's GDP per capita and $CO_2$ emissions trends (1991-2019)*

# LITERATURE REVIEW

The methodologies employed across these studies vary, encompassing panel data econometric models, random effects and fixed effects models (Bibi & Jamil, 2021), autoregressive distributed lag (ARDL) models (Usman et al., 2019; Koc & Bulus, 2020), and fully modified ordinary least squares (FMOLS) (Gokmenoglu & Taspinar, 2018). Other studies utilise dynamic panel data techniques such as the Common Correlated Effects (CCE) and Augmented Mean Group (AMG) estimations (Isik et al., 2019), and Maki's co-integration test (Gokmenoglu & Taspinar, 2018).

Common variables include carbon dioxide ($CO_2$) emissions, GDP per capita, energy consumption, trade openness, and foreign direct investment. Some studies incorporate additional variables such as institutional quality (Bibi & Jamil, 2021), financial development indicators (Sun et al., 2024), and agricultural value added (Gokmenoglu & Taspinar, 2018). Data spans several decades, with most studies covering the period from the 1970s to the 2010s.

01

### Environmental Kuznets Curve Studies

Research generally supports the EKC hypothesis globally, though with notable exceptions and regional variations, particularly in Sub-Saharan Africa.

02

### Pollution Haven Hypothesis Research

Studies suggest developed countries may relocate polluting industries to developing nations with more lenient environmental regulations.

03

### Pollution Halo Hypothesis Analysis

Research emphasizes that FDI may introduce advanced and cleaner technologies to host countries, leading to improved environmental quality.

04

### Regional and Methodological Variations

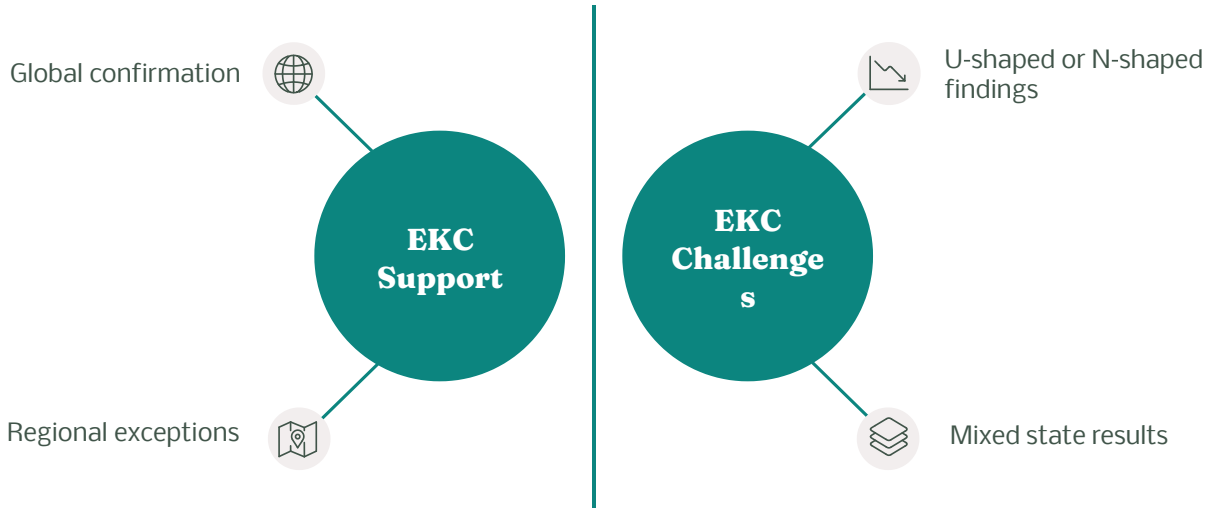
Diverse methodologies provide broad perspectives while regional studies highlight local variations crucial for targeted policy recommendations.

The results generally support the Environmental Kuznets Curve (EKC) hypothesis, though with notable exceptions and regional variations. Bibi and Jamil (2021) find support for the EKC hypothesis in all regions except Sub-Saharan Africa, indicating regional differences. Sun et al. (2024) confirm the EKC hypothesis globally, with trade protectionism having varied effects across income groups. Mahmood et al. (2023) report higher validation of the EKC hypothesis in Chinese studies using global pollution proxies and provincial data.

Conversely, some studies challenge the EKC hypothesis. Dogan and Inglesi-Lotz (2020) find a U-shaped relationship when considering the industrial share of the economy in European countries, rather than an inverted U-shape. Koc and Bulus (2020) do not support the EKC hypothesis for Korea, identifying an N-shaped relationship instead. Isik et al. (2019) report mixed results for US states, with the EKC hypothesis validated in only 14 states.

The PHH suggests that developed countries may relocate polluting industries to developing nations with more lenient environmental regulations (Abbasi, Nosheen & Rahman, 2023). This can lead to a concentration of polluting industries in "pollution havens," potentially exacerbating environmental degradation. The PHLH emphasizes regulatory disparities between countries, and FDI may be one of the factors responsible for environmental degradation in developing countries as stated by Nguyen (2020).

Despite extensive research, no studies have specifically focused on testing these hypotheses in the Botswana economy. Existing studies on these hypotheses yield conflicting conclusions regarding the impacts of trade, FDI, and population density on the environment. This research aims to fill this gap by examining the relationships between carbon dioxide emissions, GDP per capita, trade, FDI, population density, and government expenditure in Botswana using an econometric model based on the EKC, while also testing for PHH and PHLH hypotheses.



# METHODOLOGY

## Theoretical Framework

The theoretical framework for this study encompasses three central hypotheses: the Environmental Kuznets Curve (EKC), the Pollution Haven Hypothesis (PHH), and the Pollution Halo Hypothesis (PHLH). These models are particularly relevant to Botswana's context due to its rapid economic growth driven by resource extraction, increasing foreign direct investment (FDI), and ongoing environmental challenges. As a developing, resource-dependent country, Botswana presents an ideal case for assessing how economic expansion and international investment interact with environmental sustainability under varying regulatory conditions.

### Environmental Kuznets Curve

Inverted U-shaped relationship between economic development and environmental degradation

### Pollution Haven Hypothesis

FDI flows to countries with weaker environmental regulations, increasing pollution

### Pollution Halo Hypothesis

FDI improves environmental standards through advanced technologies and practices

## Definition of Variables

Carbon Dioxide Emissions ($CO_2$) serve as a key indicator for environmental degradation due to its role as a primary greenhouse gas contributing to climate change (Abbasi et al., 2023; United Nations, 2023). Its widespread monitoring and reporting by international organisations like UNFCCC make it a suitable empirical variable (United Nations Framework Convention on Climate Change [UNFCCC], 2023).

Gross Domestic Product per Capita (GDPPC) acts as a proxy for economic development, capturing overall economic activity and prosperity (Bimonte & Stabile, 2017; Juana, 2014). Trade Openness measures a country's engagement in international trade and economic integration, influencing the flow of goods, services, and capital (Nasir et al., 2021).

Foreign Direct Investment (FDI) is a significant variable in this study due to its potential influence on environmental outcomes in host countries. Government expenditure indicates the level of commitment to environmental issues through policies, interventions, and investments in cleaner technologies (Amusa & Oyinlola, 2019). The descriptive statistics for all variables are presented in Table 1.

**Table 1:** Descriptive statistics of key variables used in the study

| Variable | Mean | Description |
|---|---|---|
| CO2 | 2.893 mt per capita | Carbon dioxide emissions as environmental indicator |
| GDPPC | $5,500 | Gross domestic product per capita |
| FDINIF | $294.21 million | Foreign direct investment inflows |
| GE | $1,398.63 million | Government expenditure |
| IMPO | $2,132.78 million | Import values |

## Data and pre-estimation diagnostics

This study utilises data for Botswana for the period 1991-2019. The starting point of 1991 was chosen due to data availability and its alignment with significant structural changes in Botswana's economy, including trade liberalisation, increased foreign direct investment (FDI), and the gradual shift toward market-oriented policies. This period also captures key environmental and developmental policy evolutions, such as the implementation of the National Conservation Strategy and subsequent integration of environmental considerations into national planning. The 29-year timeframe provides a comprehensive view of long-term trends in economic growth, environmental outcomes, and the influence of FDI under varying regulatory and policy regimes. The data is obtained from the World Bank database.

The descriptive statistics reveal substantial insights into Botswana's economic and environmental dynamics. $CO_2$ emissions have a mean of 2.893 metric tons per capita, with a standard deviation of 0.484, indicating significant fluctuations in environmental impact. GDP per capita averages around $5,500, with a standard deviation of $1,698.63, reflecting economic instability and growth. FDI inflows have a mean of $294.21 million and a standard deviation of $189.45 million, suggesting shifts in investor confidence and policy changes.

Unit root tests were conducted using the Augmented Dickey-Fuller (ADF) method, which confirmed that all variables are integrated of order one, I(1), and none are integrated of order two, I(2). This satisfies the preconditions for applying the ARDL bounds testing methodology. A standard VAR was estimated for lag length selection criteria, and the AIC, SC, and HQ selected a lag 1. Furthermore, the Bounds Test was conducted to test for cointegration among the study's variables.

### Estimation Method

This study employs the ARDL approach to analyse the long-run and short-run dynamics among the variables under consideration. The ARDL methodology, introduced by Pesaran and Shin (1999), is particularly suitable for small sample sizes and can be applied irrespective of whether the underlying variables are purely I(0), purely I(1), or mutually cointegrated. This flexibility makes ARDL a robust econometric technique for investigating the existence of cointegration relationships among time-series data.

# RESULTS AND DISCUSSION

The results from the ARDL model provide critical insights into the relationship between economic growth and environmental quality in Botswana, testing the EKC hypothesis, PHH, and PHLH.

The error correction term (ECT(-1)) is significant and negative (-0.692), indicating that about 69.2% of the deviations from the long-run equilibrium are corrected within a year. This suggests a strong tendency for $CO_2$ emissions to return to equilibrium following economic shocks.

| 69.2% | $3,479 | $5,500 | 29 |
|---|---|---|---|
| **Error Correction** | **EKC Turning Point** | **Mean GDP per capita** | **Study Period** |
| Annual adjustment to equilibrium | GDP per capita threshold | Value during 1991-2019 | Years of data (1991-2019) |

The short-run dynamics reveal that the coefficient for the change in the squared GDP per capita (D(LGDPPPC2)) is positive and significant (3.046), implying that in the short run, as GDP per capita increases, the rate of $CO_2$ emissions increases at an accelerating rate. This finding suggests a U-shaped relationship between economic growth and $CO_2$ emissions, where emissions initially decrease and then increase as GDP per capita rises.

In the long run, the coefficient for LGDPPC is negative and significant (-73.405), while LGDPPC2(-1) is positive and significant (4.500). This confirms a U-shaped relationship for the EKC hypothesis in Botswana. The negative coefficient of LGDPPC indicates that at lower levels of GDP per capita, economic growth leads to reductions in $CO_2$ emissions. However, the positive coefficient for LGDPPC2 suggests that beyond a certain level of income, further economic growth contributes to increased emissions.

Foreign direct investments' long-run impact is negative and significant (FDINIF(-1) = -0.000), suggesting that long-term FDI inflows contribute to a reduction in $CO_2$ emissions, possibly through the adoption of environmentally friendly technologies brought by foreign investors. This supports the PHLH, where FDI can bring advanced technologies and management practices that improve environmental quality.

This temporal distinction in FDI effects aligns with established patterns in extractive industries. Huang et al. (2025) demonstrate that initial FDI in mining sectors typically increases emissions for 5-7 years as infrastructure development and extraction activities intensify, before cleaner technology transfer and improved management practices take effect. In Botswana's context, the diamond mining sector, which contributes approximately 30% of GDP and over 80% of export earnings, saw major FDI peak in the 1990s-2000s. This period coincided with rising emissions, while environmental regulations were strengthened only after 2010 through the Environmental Assessment Act (2011) and subsequent policy frameworks. This timeline explains the observed short-term pollution haven effects transitioning to longer-term pollution halo benefits as regulatory frameworks matured and technology transfer occurred.

The combination of a negative LGDPPC and a positive LGDPPC2 coefficient confirms the traditional U-shaped EKC for Botswana. The turning point of the EKC can be calculated as −(−73.405) 2(4.500), which gives 8.1561. The exponent of 8.1561 (e8.1561) gives the turning point as US$3,479.38 which is the GDP per capita level at which $CO_2$ emissions begin to increase in Botswana.

Considering that the minimum GDP per capita in Botswana over the study period (observed in 1991) is approximately $3,931, which is above the turning point of $3,479.38. This implies that throughout the observed period (1991-2019), Botswana has been in the phase where economic growth is associated with rising $CO_2$ emissions (see Figure 4). The mean GDP per capita for Botswana is approximately $5,500. This value is well above the turning point, indicating that on average, Botswana is in the phase of the EKC where further economic growth leads to increased $CO_2$ emissions.

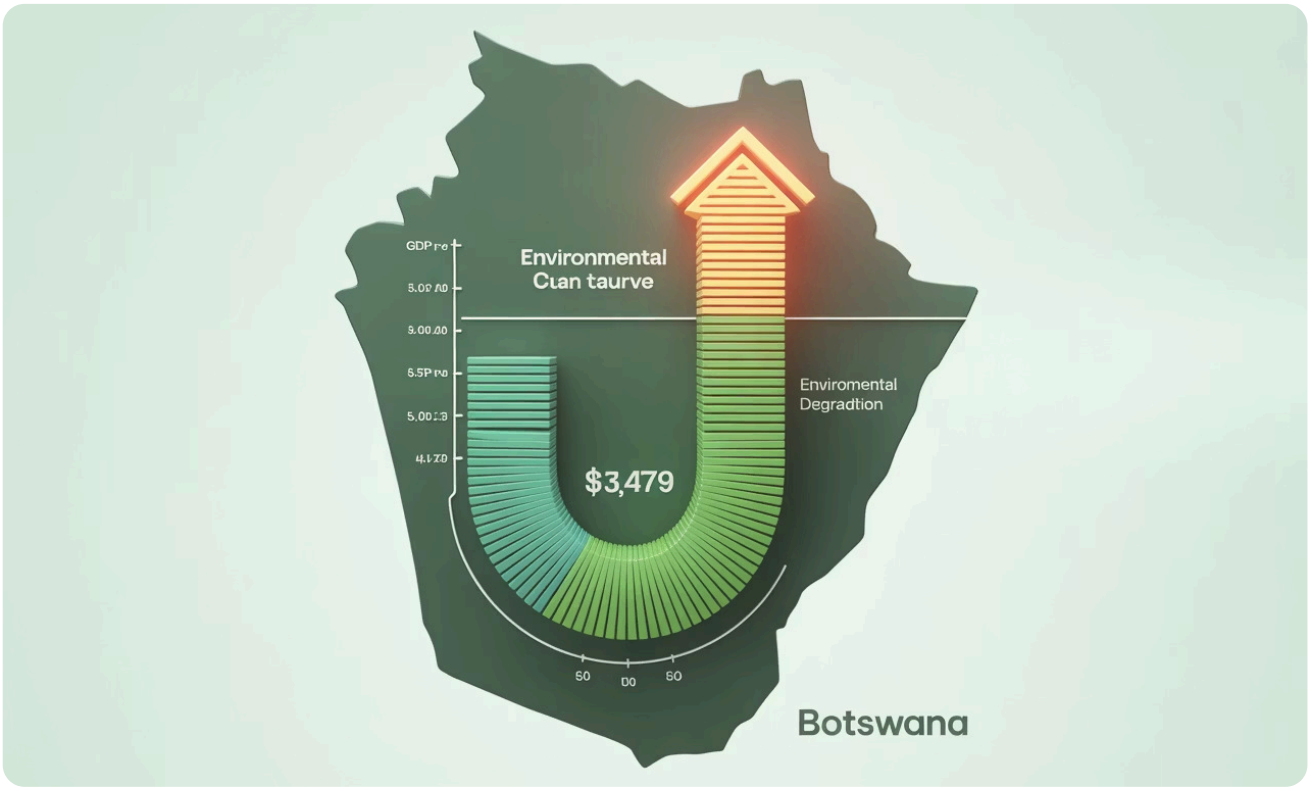



*Figure 4: Environmental Kuznets Curve for Botswana showing U-shaped relationship with turning point at $3,479 GDP per capita*

The ARDL model satisfies all residual diagnostic tests, including normality (Jarque-Bera), serial correlation (Breusch-Godfrey), and heteroscedasticity (Breusch-Pagan-Godfrey) since the p-value on each test is more than 0.05. This indicates that the model is well-specified, and the estimates are reliable.

# Environmental Impact Evidence

## Diamond Mining Environmental Footprint

Recent studies reveal the significant environmental impact of diamond mining globally. The Diamond Environmental Impacts Estimation (DEIE) model projects that annual greenhouse gas emissions from the global diamond industry will reach 9.65-13.26 Mt $CO_2$ by 2100, with mineral waste generation of 422.80-582.84 Mt and water usage of 78.68-107.95 million $m^3$ (Sun et al., 2024).

As the world's largest diamond producer by value, Botswana contributes substantially to these figures, with diamonds accounting for approximately 30% of GDP and over 80% of the country's export earnings (U.S. State Department, 2024).

### Green Technology Alternatives

#### GHG Emissions

Lab-grown diamond alternatives could significantly reduce 9.58 Mt in annual GHG emissions by 2100.

#### Mineral Waste

These alternatives could potentially save 421.06 Mt in mineral waste.

#### Water Usage

Water usage could be reduced by 66.70 million $m^3$ annually.

#### Landfill Space

Annually save 714 million cubic meters of landfill space.

#### Food Security

Contribute to feeding 436 million people through reduced resource competition (Sun et al., 2024).

### Investment Climate Context

Botswana maintains strong economic fundamentals that support green technology adoption. Standard & Poor's maintained the country's investment-grade sovereign credit rating at "BBB+/A-2" with stable outlook in March 2024, reflecting the country's capacity to attract sustainable foreign investment (U.S. State Department, 2024). This financial stability provides a foundation for implementing the recommended green technology investments and regulatory strengthening measures.

# Vision 2036 Implementation Context

## Current Economic Trajectory

Botswana's economy is positioned for growth acceleration in 2024 before returning to a coping phase in 2025, according to UNDP SDG analysis (2023). This trajectory is characterized by being 35% higher than global averages, supported by prudent macroeconomic policies and robust economic institutions, particularly around managing diamond revenue through the fast-tracked implementation of the government's Economic Recovery and Transformation Plan.

### Vision 2036 Strategic Alignment

The study's findings directly support Botswana's Vision 2036 transformational agenda, which aims to transform the country from upper middle-income to high-income status by 2036. The four strategic pillars of Vision 2036 align with the research recommendations:

**Sustainable Economic Development**
Supports the green technology investment recommendations

**Human and Social Development**
Addresses equity concerns raised in policy implications

**Sustainable Environment**
Directly targets the environmental degradation challenges identified

**Governance, Peace and Security**
Encompasses the institutional capacity building recommendations

### UN Cooperation Framework 2022-2026

The United Nations Sustainable Development Cooperation Framework provides institutional support for implementing the study's recommendations. The framework specifically pledges to support fulfillment of Vision 2036 and National Development Plan 11, while ensuring national implementation of the 2030 Agenda for Sustainable Development (United Nations Botswana, 2024).

### SDG Progress Indicators

Current challenges include high inequality, structural unemployment, and a small domestic private sector focused on non-tradables, with poor outcomes on health and education indicators (United Nations Development Programme, 2023). These align with the study's emphasis on addressing disproportionate environmental burdens on rural communities, women, youth, and subsistence farmers.

# RECOMMENDATIONS AND CONCLUSIONS

The study confirms the traditional U-shaped EKC hypothesis for Botswana, highlighting a significant relationship between economic growth and environmental quality. The positive coefficient of $LGDPPC^2$ and the negative coefficient of LGDPPC support a U-shaped relationship, indicating that while initial economic growth leads to reduced $CO_2$ emissions, further growth results in increased emissions.

The estimated turning point for the EKC is approximately USD 3,479.38. When compared to the minimum around USD 3,931 and mean around USD 5,500, respectively, this suggests that Botswana is in the post-turning point phase of the EKC, where continued economic growth is associated with environmental degradation.

However, this turning point appears unusually low compared to international evidence. Hussain et al. (2023) demonstrate that most developing countries experience EKC turning points between USD 8,000-15,000 per capita, while Leal and Marques (2022) show that resource-dependent economies typically reach environmental improvement thresholds at even higher income levels. This suggests that Botswana, with its GDP per capita in 2019 of USD 6,485, remains well within the ascending phase of the EKC where continued economic growth is associated with increasing environmental degradation. The relatively low calculated turning point may reflect the dominance of extractive industries in Botswana's economy, which typically exhibit different environmental-income dynamics compared to diversified economies.

Moreover, the study provides mixed evidence for the Pollution Haven Hypothesis (PHH) and the Pollution Halo Hypothesis (PHLH). In the short term, the positive impact of FDI on emissions supports the PHH, implying that foreign investors may take advantage of Botswana's relatively weak enforcement of environmental standards. However, in the long term, the negative relationship between FDI and emissions supports the PHLH, suggesting that sustained foreign investment can introduce cleaner technologies and enhance environmental performance over time.

### Green Technology Investment

Prioritize investments in renewable energy infrastructure and clean technologies aligned with National Energy Policy (2016) and Renewable Energy Policy (2019).

### Regulatory Strengthening

Enhance enforcement capacity through Environmental Assessment Act (2011) and improved monitoring systems for mining and industrial operations.

### Sustainable FDI Attraction

Develop policies to attract environmentally friendly foreign investment while mitigating short-term pollution risks through performance standards.

### Institutional Capacity Building

Strengthen environmental institutions, improve cross-ministerial coordination, and invest in environmental data infrastructure for better monitoring.

## Policy Implications

These findings have critical policy implications for Botswana. To mitigate the environmental impact of economic growth (Wang et al., 2024), the country should prioritize investments in green technologies and renewable energy infrastructure. However, such transitions must be grounded in Botswana's specific context, considering its regulatory capacity, technological readiness, and political economy. Given the relatively limited enforcement capacity of environmental institutions (Mutemeri, 2024), efforts to strengthen regulations should be paired with targeted institutional support, capacity-building initiatives, and community-based enforcement mechanisms, particularly in rural areas where state oversight is weaker.

Incentivizing foreign direct investment (FDI) that introduces environmentally friendly technologies remains crucial, especially given the Pollution Haven and Pollution Halo dynamics observed. To avoid short-term environmental degradation from FDI, Botswana must establish clearer environmental performance standards, improve cross-ministerial coordination (International Monetary Fund, 2024), and enforce environmental impact assessments (EIAs) through well-resourced and transparent agencies.

From an equity perspective, policies should deliberately address the disproportionate environmental burdens borne by rural communities, women, youth, and subsistence farmers–groups most affected by climate shocks, land degradation, and resource scarcity (Chikuta et al., 2024; Rankoana, 2024). Participatory governance models and decentralized decision-making can empower these communities to shape local environmental solutions.

These context-responsive measures are essential for Botswana to achieve inclusive and sustainable economic growth while effectively managing $CO_2$ emissions and environmental degradation in line with Vision 2036, the National Development Plan 12 (NDP12), and Sustainable Development Goals (SDGs), particularly SDG 7 (affordable and clean energy), SDG 9 (industry, innovation, and infrastructure), and SDG 13 (climate action).

These recommendations are supported by evidence from comparable diamond-producing countries. South Africa's Mining Charter (2018) demonstrates that comprehensive regulatory frameworks can achieve significant environmental improvements in mining operations (Government of South Africa, 2018). Similarly, Canada's Metal and Diamond Mining Effluent Regulations have successfully reduced water contamination from mining operations while maintaining economic viability (Environment and Climate Change Canada, 2018). These examples provide practical blueprints for Botswana's policy implementation.

Future research should explore sector-specific impacts of economic activities on environmental degradation and consider other pollutants beyond CO2 to provide a comprehensive understanding of the EKC dynamics in Botswana. Additionally, integrating more advanced econometric techniques such as the Quantile ARDL (QARDL) model could offer deeper insights into the distributional effects of income on environmental quality across different quantiles.

# ACKNOWLEDGEMENT

The author(s) gratefully acknowledge the support of the 2024 Humboldt Residency Programme, Alexander von Humboldt Foundation, in making this special issue Bridging power and knowledge: Addressing global imbalances in knowledge systems for sustainable futures possible.

# CONFLICTS OF INTEREST

The author declares no conflict of interest

# FUNDING

This project received funding from the 2024 Humboldt Residency Programme of the Alexander von Humboldt Foundation.

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**Received:** January 12, 2025
**Accepted:** July 21, 2025
**Published:** October 31, 2025

**Citation:**

Lovemore, T. & Thabeng, M. M. (2025). Environmental degradation and economic performance in Botswana: A test of the environmental Kuznets curve, Pollution Haven and Pollution Halo Hypotheses. *SustainE,* 3(1), 140-163. In A. Akinsemolu, A. Eimer, & S. Iqbal (Eds.), *Bridging power and knowledge: Addressing global imbalances in knowledge systems for sustainable futures* [Special issue]. https://doi.org/10.55366/suse.v3i1.7