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Testing the Environmental Kuznets Curve and Pollution Haven Hypothesis: Using the Dynamic Interaction of Macroeconomic Variables in Zambia

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Abstract

Purpose: This study investigates the dynamic relationship between macro-economic variables, specifically FDI and economic growth (GDP per capita), and their impact on GHG emissions in Zambia. Using time series data from 1990 to 2022, this investigation tested the Environmental Kuznets Curve (EKC) and Pollution Haven Hypothesis (PHH).

Materials and Methods: The econometric analysis made use of the Vector Error Correction Model (VECM) to evaluate the short run and long run relationship among the variables while the granger causality test was used to analyze the causal relationship among the variables.

Findings: The findings revealed that the EKC does not hold in Zambia, indicating a U-shaped relationship between economic growth and GHG emissions. Furthermore, FDI in Zambia supports environmental sustainability, aligning with the Pollution Halo Hypothesis (PHAH) rather than the PHH at least at the low level of current Zambia's output. The granger causality results indicated that there exists a positive unidirectional causal relationship from GDP per capita to GHG emissions and no causality relationship among the rest of the variables.

Unique contribution to Theory, Practice and Policy: These results provide insights for policymakers to balance economic growth with environmental sustainability hence the study suggested policy recommendations aimed at strengthening regulations, promoting green technology, and attracting sustainable foreign investment.

Keywords: *Environmental Kuznets Curve (EKC), Pollution Haven Hypothesis (PHH), Pollution Haven Hypothesis (PHAH), Foreign Direct Investment (FDI), Green House Gas (GHG Emissions)*

JEL Classification: *B4, C1, C3, D2*

INTRODUCTION

Environmental degradation has increasingly become a serious challenge worldwide and in the response to this, The United Nations (UN) member countries in 2015 adopted the 17 Sustainable Development Goals (SDGs) to address the different challenges facing countries across the world and goal number 13 is “take urgent action to combat climate change and its impact.” (United Nations Report, 2012). Greenhouse Gases (GHGs) such as Nitrous Oxide (N_2O), Carbon Dioxide (C_2O), Methane (CH_4) and Fluorinated gases are regarded as important contributors to climate change while at the same time these GHGs emissions are products of economic activities that drive economic growth and development (Mladenovic et al., 2016). The impacts of climate change in African countries are worrisome such that many studies for example those done by Niang et al., 2014; Rose, 2015; Hummel, 2015 highlight that the continent is the most vulnerable to the impact of climate change owing to the high exposure, poor adaptive capacity and high dependence on agriculture for economic sustainability and food security (Awojobi, 2017).

The ongoing conversation about climate change has focused on human-induced factors and anthropogenic activities that contribute to both environmental degradation and economic development (IPCC, 2014). Therefore, the nexus between macroeconomic indicators such as economic growth and foreign direct investments (FDI) and environmental degradation can be widely explained through the Environmental Kuznets Curve (EKC) and Pollution Haven Hypothesis (PHH). The EKC highlights an inverted U-shaped relationship between economic growth and environmental degradation, while the PHH argues that countries with weaker environmental laws attract polluting foreign investments. The PHH is particularly relevant in Africa, where Chinese FDI flows doubled between 1998 and 2018, influencing trade, economic growth, and environmental outcomes in the receipt countries (China Africa Research Initiative, 2020). Two perspectives on the economic-environment nexus persist: one advocating growth suspension for sustainability and another proposing simultaneous achievement through mitigation (Alagidede et al., 2015; IPCC, 2014).

Since independence, Zambia's economy has transitioned from a predominantly rural base to industrialization, leveraging its abundant natural resources like agricultural land, minerals, and forestry (Ministry of Green Economy and Environment, 2024). Early diversifications reduced reliance on copper, leading to export focused policies like the 1977 Industrial Development Act. In the 1990s, reforms such as privatization and Structural Adjustment Programs (SAPs) aimed to boost the economy and attract foreign investment (Chitonge. et al, 2024). However, the economy has largely depended on the mining industry since the 1920s despite the gradual diversification of economic activities over time (ibid). Today, initiatives like the 8th National Development Plan aim to achieve Vision 2030 by positioning Zambia as an upper-middle-income nation. Regional integration efforts with SADC and COMESA, coupled with investments from nations like China and the UK, have boosted Zambia's FDI to 53.5% of GDP by 2023 (UNCTAD, 2023). However, balancing economic growth and environmental sustainability remains critical, as economic activities contribute to deforestation, toxic emissions, and climate change impacts, such as droughts and energy shortages (IGC Report, 2018; USAID, 2015). Zambia's greenhouse gas (GHG) emissions, primarily from land-use changes (61% in 2011), exacerbate global and national environmental concerns, including global warming and ozone depletion (Mahsa Karimi, 2014; Spash, 2020).

Problem Statement

In the pursuit of economic growth, Zambia has increasingly embraced economic openness since the privatization era. The economy has experienced persistent positive GDP growth rate for the past two decades except the negative growth rate of -2.79% experienced in 2020 because of the COVID-19 pandemic (World bank, 2022). However, the increase in anthropogenic activities to increase economic growth has identified potential to affect the environmental state of the country.

Zambia has experienced a rise in GHG emissions over the decades and according to the National Policy on Climate Change (2016), the projected total of GHG emissions from all sectors if correct mitigation efforts are not implemented will be a total of 216.8 million tones Carbon Dioxide equivalent. This increases environmental degradation and the rate of climate change, which further has an impact on economic activities as it affects agriculture outputs, energy production, mining, etc. The results of environmental degradation such as low agriculture output which reduces food security in Zambia, increasing droughts and floods, reduction in international trade due to the rising risk of conflict over threatened natural resources such as land and forestry causes more strain on the government's effort to generate a diversified export-growth economy (Simiyu, 2017).

Since 1991, the Government of Zambia has aimed to adopt several strategies to ensure there is an increases inflow of FDI to benefit from its perceived benefits and aid in increasing economic activities. Subsequently, Zambia received a high share of FDI inflows, specifically in 2012, 14% of China's FDI to Southern Africa flowed into Zambia and Zimbabwe making a total of $292million and $287million inflow of Chinese FDI into each country respectively. In 2013, the country received a total of $2.1 billion recording the highest total FDI inflows for the period of 1990 to 2018 (Doku, et al., 2017).

However, there is unexplored and limited evidence on the actual empirical impact of these economic indicators on the environment in Zambia. Hence the overarching goal of the study is to empirically evaluate the environmental impacts of the economic indicators i.e. FDI and economic growth. The econometrics evaluation will simultaneously validate the applicability of the EKC and the PHH in the Zambian economy. By understanding the dynamics, the study will provide valuable evidence-based insights and recommendations towards policies needed to promote sustainable economic development.

This study considers the following hypothesis:

i. The EKC does not hold between economic growth and GHG emissions in Zambia;
ii. The PHH does not hold between FDI and GHG emissions in Zambia;
iii. There is causal relationship between GHG emissions and the independent variables (GDP per Capita, FDI, trade openness and energy use).

To the best of the author's knowledge, despite the vast world literature on the environmental impact of economic indicators there is inadequate research done exclusively on Zambia. Limited number of studies have investigated the EKC with a focus on deforestation rate and carbon dioxide emissions. However, according to the author's knowledge, there is little to no information on the investigation of the impact of FDI on environmental sustainability in Zambia as well as on the investigation of economic activities on the environment while employing GHG emissions as an environmental measure.

By using total GHG emissions as a comprehensive environmental indicator, this study offers a broader environmental perspective and extends the scope of analysis beyond carbon dioxide which was used by Mudenda (2016) or deforestation which was used by Makondo et al. (2021). In making use of a total GHG emissions, the study aligns with recent policy insights from PMRC (2021) which emphasizes Zambia's total climate vulnerability and the need for inclusive environmental indicators. Furthermore, the dual testing of both EKC and PHH using a dynamic time series framework, specifically the VECM adds another valuable contribution putting into consideration that past related studies exclusively on Zambia environmental have not concurrently tested for both EKC and PHH within the same analytical framework. The simultaneous testing allows for a deeper exploration of how GDP per Capita and FDI interact to shape Zambia's environmental outcomes over time.

The relevance of the study is further underscored by Zambia's economic trajectory which has undergone increased liberalization and need for FDI inflows, especially in the mining and manufacturing sector (Mudenda, 2009). The inclusion of the impact of FDI directly addresses the raising concerns raised by Zambia Development Agency (ZDA) about the environmental impact of increasing FDI especially in the country's leading economic sectors. These trends present a compelling case to evaluate the PHH in relation to FDI inflows. Additionally, evidence-based insights into the macroeconomic drivers of environmental degradation will be provided which will complement policy driven research which highlight the importance of climate resilient development but lack econometric rigor in testing the theoretical relationship between growth, investment, and emissions (Rawlins and Kalaba, 2020).

LITERATURE REVIEW

Theoretical Review

The theories highlighted are among the many other theories that add to the literature on the relationship between environmental pollution, economic growth and FDI. This study is therefore based on three theories which have been discussed below:

Environmental Kuznets Curve (EKC) Theory

The Environmental Kuznets curve theory proposes an inverted U-shaped correlation between environmental degradation which is the opposite of environmental sustainability and economic growth. It suggests that environmental sustainability initially worsens during the early stages of economic growth until a particular level of development is obtained which is the peak or turning point at which environmental sustainability begins to improve (Ma et al, 2021). The hypothesized relationship was first formally inverted by Kuznets (1955), who indicated the evidence of an inverted U-shaped link between income and the growth of income.

The Kuznets curve was therefore applied to environmental economics where the level of income and economic development was linked to the quality of the environment. However, the term environmental Kuznets Curve hypothesis can be traced back to Grossman and Krueger (1991), who postulated that in the case of selected economies, environmental pollution would increase with an increase in income until a certain level of income is attained. After the threshold is achieved, the environmental pollution will begin to decline as the income increases. This then implies that when economies grow, it begins to pose better technologies that are environmentally friendly over time and an increase in incomes leads to a demand for a more sustainable environment. The figure below shows the EKC hypothesis:

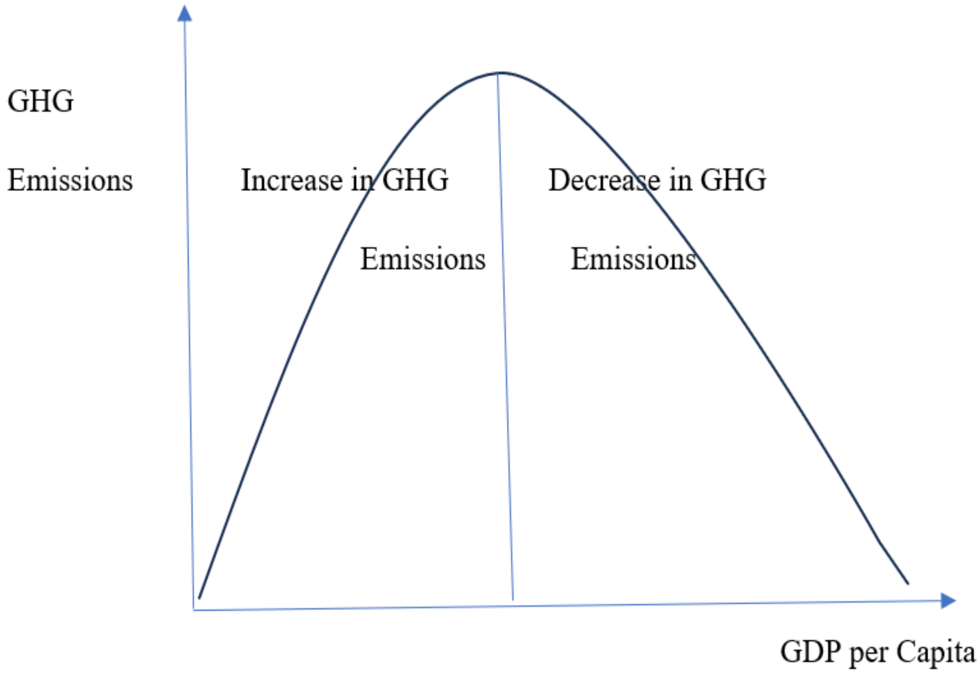

Figure 1: Environmental Kuznet Curve (EKC)

This theory serves as a valuable tool for investigating whether there exists a certain level of economic growth that enhances environmental sustainability. This is vital for Zambia, a country experiencing on going industrial development and urbanization because the EKC turning point is important for balancing growth with sustainable environmental policies. The underlying idea is that as an economy progresses, there is a policy shift to more environmentally friendly approaches of production that is after the economy has attained a certain level of economic development. (Baajike et. al, 2022).

Pollution Haven Hypothesis (PHH)

The discussion between FDI and the quality of the environment of the host country is still uncertain. The hypothesis between FDI and the environmental quality is commonly divided into two basic views which are the Pollution Haven Hypothesis (PHH) and Pollution Halo Hypothesis (PHAH) (Akbulut and Yereli, 2023).

The PHH, initially formulated by Pethig (1976) and Walter and Ugelow (1979) by demonstrating how environmental rules may affect the flow of foreign capital. The hypothesis was later followed up by other researchers such as Copeland and Taylor (1994) who within the framework of the North-South trade under the North American Free Trade Agreement (NAFTA), establishes a link between environmental regulation stringency, trade and investment patterns with the level of pollution in a country (Gill et al., 2018).

According to Copeland and Taylor (1994), the hypothesis posits that trade liberalization would prompt firms that produce pollution-intensive goods to relocate from countries with strict environmental regulations particularly developed countries to developing countries that have comparatively weaker environmental regulations. This implies that countries in the developmental stages that are seeking to increase FDI and open their trade boarders in order to increase developmental activities, such as Zambia and other numerous African nations, could potentially serve as havens for industries and goods with high pollution intensity originating from more developed countries.

The principal assertion of the hypothesis is that the migration of highly polluting industries occurs through the international trade of goods and services as well as foreign direct investment. This is significant for Zambia as it raises critical concerns regarding the country's openness to FDI without sufficiently and relatively strong environmental regulations as compared to developed countries. If environmental protective policies are in place, long term environmental degradations and resource depletion due to unregulated FDI inflows. Basically, the hypothesis suggests that firms, driven by the pursuit of cost savings, may opt for locations where environmental standards are less demanding which allows them to operate with fewer restrictions. This in turn could result in potentially lowering production costs facilitated by the underpricing of environmental resources in developing countries (Spash, 2020).

Pollution Halo Hypothesis (PHAH) Theory

According to the PHAH, FDI may improve environmental welfare when multinational enterprises transfer high production standards and clean technologies to the host countries which thereby reduces the level of pollution in the host country (Hubler and Keller, 2010). This hypothesis therefore indicates that FDI has more emission-free production and improvement of the environment due to clean industrial and knowledge transfer (Abbasi et al., 2023).

Generally, the PHAH is expected to work well in economies with corrected price signals. For example, according to Nordhaus (2013), for policies to effectively combat climate change, the market price signals should accurately reflect environmental costs. In this context, the relevant price is that of goods and services produced through FDI and ideally the market price of products associated with higher GHG emissions should be relatively higher than that of products generated through cleaner production processes. The pricing differential should arise from the stringent environmental requirements imposed by host countries, which internalize the environmental costs of production. The elevated prices signal to consumers which goods and services are pollution intensive, thereby discouraging their consumption. This therefore encourages investors and producers to utilize cleaner production process, stimulate technological innovation and reduce the complexity of environmental decision making by embedding essential information within price structure (ibid).

Therefore, according to Sapkota and Bastola (2017), if the effect of FDI on environment is positive reflecting PHAH, then the current policies on FDI would be appropriate for that particular country. The conditions under which FDI inflows reduce emissions and improve the environment largely depends on currently implemented environmental policies. Investments that do not meet the standards set by the host country will therefore direct their investments to countries with weaker environmental regulations as they will avoid incurring additional costs to regulate or imitate their GHG emissions (Akbulut and Yereli, 2023). The PHAH offers an optimistic position for Zambia where properly managed FDI can drive green transformation by encouraging cleaner technologies and supporting the country's transitions towards a green economy aligned with the Vision 2030.

According to Grossman and Krueger (1991), the validation of these two theories can be validated based on the scale composition and technological impacts. The scale effects shows that an increase in FDI will increase the economic activity of the host country which will increase the energy composition and increase environmental degradation hence supporting the PHH while the technological impacts shows that FDI is a transition mechanism for more efficient and clean technology transfer. According to the technology impact, countries would improve their environmental quality by making use of efficient and clean technologies hence supporting the PHAH (Liang, 2008).

Empirical Review

Economic Growth and Environmental Sustainability

A study conducted by Omojolaibi (2010) using panel data estimation methods examined the relationship between economic growth and environmental quality in Ghana, Nigeria and Sierra Leone from 1970 to 2006. The results showed from the pooled ordinary least squares regression confirmed the existence of the environmental Kuznets curve in the three selected countries. A similar study conducted by Adu and Denkyirah (2017) on some western African countries using panel data set from 1970 to 2013 found that economic growth leads to a significant increase in the carbon emissions in the short run, indicating that the environmental Kuznets curve hypothesis does not exist in west Africa.

Other studies have explored the relationship economic growth and environmental sustainability and simultaneously testing whether the EKG exists or not using other indicators for environmental sustainability. For example, a study conducted by Ahmad et al. (2011) employed the environmental sustainability index as an indicator for environmental sustainability. Using a panel regression data analysis for a 4-year period from 2001 to 2005, the study anticipated a U-shaped Kuznets curve considering that the environmental sustainability index is the inverse of the environmental deterioration index which produces an inverted U-shaped curve if EKC exists. However, the results showed that an inverted U-shaped curve exists with the use of the environmental sustainability index, indicating that the EKC does not exist in the selected developing countries.

A single country study focusing on the Kenyan Economy was conducted *by* Simiyu (2017), the paper examined the applicability of the EKC in Kenya and the effects of trade openness on the environment. Time series data from 1960-2012 was used with environmental quality proxied by ecological footprint. The empirical results showed that the real GDP per capital has a negative effect on environmental quality in the long run and therefore the EKC hypothesis is not valid for Kenya while the trade openness has a negative effect on the environment in the short run and a positive effect in the long run.

Additionally, Makondo et al. (2021) investigated the existence ECK hypothesis in Zambia using time series from 1990 to 2020 while employing deforestation to signify environmental degradation as the dependent variable. Independent variables included energy consumption, economic growth, population growth and trade openness. The ARDL bounds test was adopted for co-integration and the VECM- Granger causality test to understand the nexus between independent variables and deforestation. In the short run, a 1% rise in economic growth resulted in a 3.5% rise on average ceteris paribus in deforestation variables while in the long run, a 1% increase in economic growth increased deforestation by 2.2%. Hence Makondo et al. (2021) concluded that EKC hypothesis did not exist in Zambia during the considered in the paper. Similar to this finding, another Zambia based study by Mudenda (2016) showed that EKC was not applicable for the period of 1971 to 2010. The study employed Dynamic OLS and VECM as its methodology while making use of Carbon Dioxide as the independent variable, Real GRP, electricity consumption and trade as the dependent variable.

Foreign Direct Investment and Environmental Sustainability

The various studies in literature have used various variables in explaining PHH. Some have used FDI inflows as the independent variables while others have made use of net export or trade openness. There is also a variation in the measurement of environmental variable, others have used measurement of pollution (greenhouse gases, carbon dioxide, Sulphur dioxide etc.), environmental taxes and permit fees, deforestation rates, public awareness of environmental problems etc. (Ayadi, 2019).

A study conducted in Nigerian analyzes the contribution of trade liberalization and FDI inflows on economic growth and analyzes the impacts of integration on the Nigerian environment using ordinary least squares (OLS), cointegration and error correction mechanism using data from 1970 to 2012. The study concluded that FDI inflows significantly fueled pollution supporting the PHH while trade openness is beneficial in the short run and long run. (Ayadi, 2014). These results of the Nigerian economy are also in line with Riti and Kamah (2015) who also explored the impact of trade liberalization and FDI inflows in Nigeria using the error correction model and cointegration on data from 1981 to 2013. The results also found that FDI inflows worsen the environment (CO_2 emissions) in the long run hence supporting the existence of PHH in Nigeria.

Another common route in literature is for other studies to employ trade openness in place of FDI in PHH or PHAH validation. For example, Dingiswayo et al. (2023) explored the international trade and environmental quality in South Africa from 1994 to 2018 using the Autoregressive Distributive Lag (ARDL) bounds and the Granger Causality test to examine both the long run and short run relationship and provide insight into the direction of causality between the variables. The study revealed a significant and positive relationship between trade openness and carbon emissions in both long run and short run and the granger causality test indicated a unidirectional causality from trade openness to environmental quality. The results support the existence of PHH indicating that an increase in trade openness in South Africa leads to environmental degradation through increased carbon emissions

Further, the impact of economic growth, trade openness and manufacturing in India by (karedla et al., 2021) made use of the ARDL to examine the relationship between CO_2 emissions, trade, manufacturing and GDP per capita. The study employed time series data from 1971 to 2016 and resulted in the finding that there exists a long run relationship between CO_2 emissions and other variables. Trade openness significantly reduces CO_2 emissions indicating the support of PHAH whereas manufacturing and GDP have a significantly and positive impact on CO_2 emissions in the long run, which does not support the existence of EKC for the period considered.

A panel study by Longe et al. (2020), studied the relationship between trade and environmental sustainability in Africa using data from 21 countries for the period 2000-2014. Results from the pooled ordinary least square analysis revealed an inverse relationship between environmental degradation and trade supporting the existence of PHAH. While results from the fixed effects analysis revealed that trade had a positive relationship with environmental degradation in Africa. Also, the findings from the pooled mean group analysis revealed that trade could lead to an increase in environmental pollution in the long run supporting the existence of PHH. Aliyu (2005) analyzed the effect of dirty FDI on CO_2 total emissions for host countries with the use of disaggregated and panel data for 25 OECD countries. The study concluded that FDI inflows insignificantly explains pollution level and energy use in 14 OECD countries supporting the PHH.

In contrary, Danladi and Akomolafe (2013) utilized time series data between 1977 and 2010 found that there is no causality between CO_2 emissions and FDI indicating the non-applicability of PHH in Nigeria. However, another study in support of the pollution haven hypothesis was conducted by Cole et al. (2008) who accessed the extent to which FDI influences the energy intensity of firms in Cote d'lvoire, Mexico, Venezuela and Ghana and concluded that in each of these countries FDI reduces the energy intensity of plants suggesting that FDI improves the environmental sustainability in each of these countries and conclusively supporting the PHAH

Other studies such as Grossman and Krueger (1995) found that FDI negatively affect the environment through pollution and excessive extraction of natural resources following the rise in consumption and economic activities. Frankel (2008) also presented a similar argument to support the finding that FDI increases Sulphur Dioxide (SO_2) emissions which is released mainly from mining extraction into the environment supporting the pollution haven hypothesis.

Following the vast world literature review and narrowing it to the limited Zambian based studies, this study addresses a critical gap by employing total GHG emissions as a more encompassing indicator of environmental aspect as compared to the studies by Makondo et al. (2021) and Mudenda (2016). Furthermore, the inclusion of FDI into the empirical model and jointly testing the EKC and PHH, extends the existing literature by providing a more holistic assessment of the dynamic relationship of the macro economic variables of interest with GHG emissions in Zambia.

MATERIALS AND ECONOMETRICS METHODS

The first part of this section shows the overall trends of economic growth, FDI and GHG from 1990 and 2022 in Zambia. The second part consists of the empirical and econometric analysis.

Overview of Zambian Historical Trends

This section discusses the Zambia background and data trends for the three main variables of discussion in this paper. The period covers a period of 33 years (1990 to 2022).

Zambia`s total GHG emissions has experienced an increasing linear trend over the years from 1990 to 2022. The country has experienced persistent positive annual percentage changes from 2012 to 2019 and experienced a 1.37% decline in 2020 change from 2019. In 2011, the LUCF sector accounted for approximately 61% of the country's GHG emissions, energy sector accounted for 19%, and agriculture accounted for 17% while industrial processes accounted for 1%. The land use change is a global environmental concern as it is one of the remarkable causes of anthropogenic destruction of the environment (USAID, 2015). Specifically, greenhouse gas emissions are a major contributor to the environmental problems such as global warming, acid rain, climate change, and ozone exhaustion. These environmental problems have generated further problems such as low agriculture production due to droughts and floods, energy production, human health and the overall social and economic welfare of humanity (Spash, 2020). The graphs below show the trend in the GHG emissions with GDP per capita and FDI over the past 33 years.

The graph below illustrates the relationship between GHG emissions and the GDP per capita. It shows that as GDP per capita increases, GHG emissions initially rise, suggesting a positive correlation between economic growth and environmental degradation

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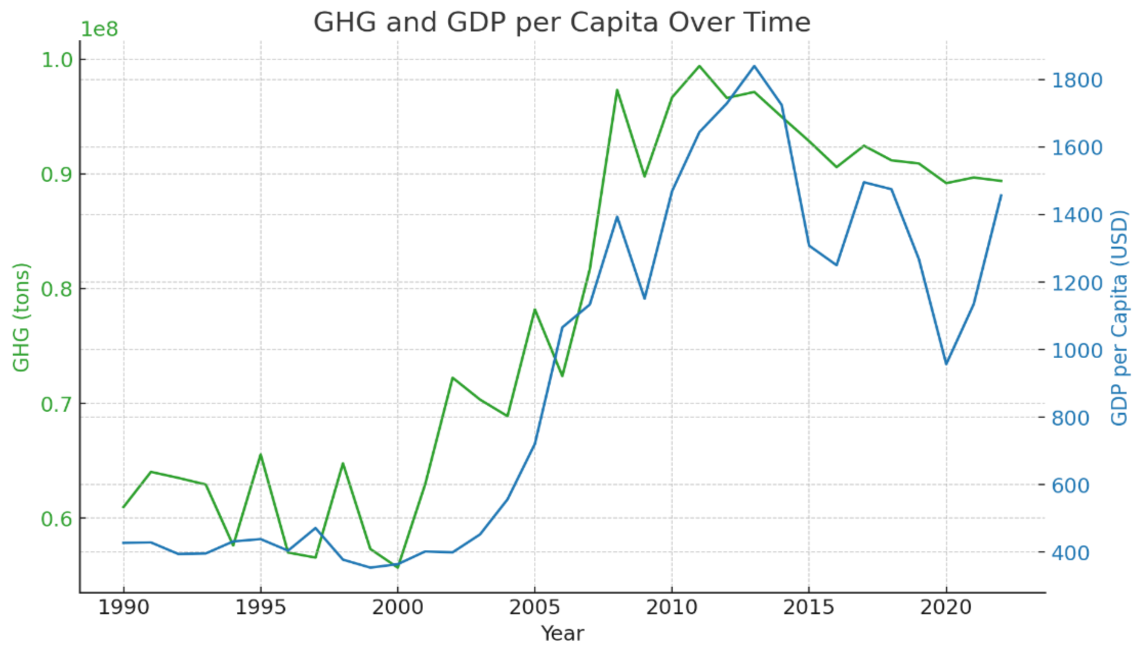

Figure 2: Green House Gas (GHGs) Emissions and GDP per Capita Trend in Zambia.

Data Source: Annual greenhouse gas emissions by world region, 1990 to 2022 (ourworldindata.org)

Additionally, the next graph below shows the trend between GHG emissions with FDI. From the trends, periods of high FDI sometimes coincide with rising emissions. However, in some periods, FDI is accompanied by decreasing emissions, possibly indicating investments in sectors with lower environmental impacts.

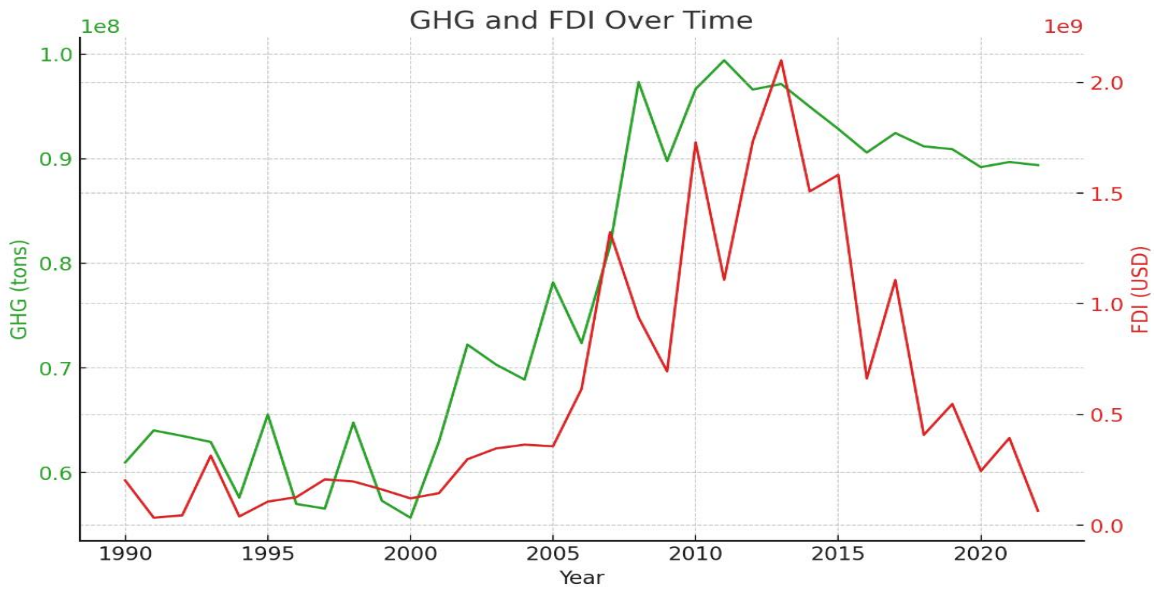

Figure 3: Green House Gas (GHGs) Emissions and FDI Trend in Zambia

Data Source: Annual greenhouse gas emissions by world region, 1990 to 2022 (ourworldindata.org)

Therefore, in the pursuit of economic growth, Zambia has increasingly embraced economic openness since the privatization era. The economy has experienced persistent positive GDP growth rate for the past two decades except the negative growth rate of -2.79% experienced in 2020 as a result of the COVID-19 pandemic (World bank, 2022). The Government of Zambia has also aimed to adopted several strategies to ensure there is an increases inflow of FDI so as to benefit from its perceived benefits and aid in increasing economic activities. Subsequently, Zambia received a high share of FDI inflows, specifically in 2012, 14% of China's FDI to Southern Africa flowed into Zambia and Zimbabwe making a total of $292million and $287million inflow of Chinese FDI into each country respectively. In 2013, the country received a total of $2.1 billion recording the highest total FDI inflows for the period of 1990 to 2018 (Doku, et al., 2017). The FDI inflows have then declined since 2013 and the economy has been experiencing challenges in the balance of payment (Mutambo et al., 2025). To address some of the challenges, the Government of Zambia put in place the 8th National Development Plan (8th NDP) which is a cornerstone to achieving the Vision 2030, which is to elevate Zambia into an industrialized, upper middle-income nation by 2030 hence promoting economic growth activities including the call to attract FDI inflows.

However, there is unexplored and limited evidence on the actual empirical impact of these economic indicators on the environment in Zambia. Hence the overarching goal of the study is to empirically evaluate the environmental impacts of the economic indicators i.e. FDI and economic growth. The econometrics evaluation will simultaneously validate the applicability of the EKC and the PHH in the Zambian economy. By understanding the dynamics, the study will provide valuable evidence-based insights and recommendations towards policies needed to promote sustainable economic development.

Empirical and Econometric Steps

The empirical analysis applied the econometrics procedure in examining the dynamic impacts of economic growth and FDI inflows on GHG emissions. The paper used time series data for the period of 1990 to 2022 years covering a period of 33 years. The study utilized three different variables and two control variables i.e. GHG emissions as a proxy for the environmental impact, GDP per capita as an indicator for economic growth and FDI inflows. As control variables, the model included trade openness (the sum of exports and imports as a percent of GDP) and the annual total energy use given its relationship with economic growth and greenhouse gas emission. Data sources included World Bank Indicators for GDP per Capita, FDI, Trade openness, Total energy use while GHG emissions was sourced from Our World Data database. All variables were transformed to logs for easier interpretations except for Trade openness as it is expressed in percentages.

The theoretical framework of this paper was based on the IPAT identity, which states that environmental impact is a product of Affluence (GDP), Technology and population as shown below;

$$I = P * A * T \quad \text{..........eq. (1)}$$

This specification shows that when one factor changes, its affect the environmental impacts directly while holding the other variables constant (YORK et al., 2003). Nevertheless, in order to overcome such shortcomings of the IPAT model Dietz and Rosa (1994) specified the stochastic Impact by Regression on the Population, Affluence and Technology (STIRPAT) as a Cobb-Douglas function. Therefore, this paper adopted a modified STRIPAT model with an addition of some variables due to their empirical support and dropping of some based on the data availability. The modification was be done based on York et al (2003), who stated that the model can be modified either by adding other variables as long they qualify the theoretical multiplicative specification. The modified STRIPAT model is shown below:

Model 1:

$$lnGHG = \beta_o + \beta_1 lnGDPG_t + \beta_2 lnFDI_t + \beta_3 lnTO_t\ \beta_4 lnEU_t + e_t \text{……………eq. (2)}$$

In order to test the EKC hypothesis, a quadratic term of GDPG was generated by squaring the values of GDPC and included into the modified model given by equation (2) to formulate model 2 as shown by equation (3) below.

Model 2:

$$lnGHG = \beta_o + \beta_1 lnGDPG_t + \beta_2 lnGDPG^2 t + \beta_3 lnFDIt + \beta_4 lnTO_t + \beta_5 lnEU_t + e_t \text{ ……… eq. (3)}$$

GDPG represents the initial stage of gross domestic product growth, $GDPG_t^2$ is the beyond initial stage of gross domestic product growth. From Model 2, the coefficients, β_0, β_1, β_2, β_3, β_4 and β_5 are the elasticities. With β_1 and β_2 as the economic growth elasticities used to assess the applicability of EKC. To test the EKC in this case, the elasticities of GDPG and $GDPG_t{}^2$ will be compared and if $\beta_1 > 0$ *and* $\beta_2 < 0$ then the EKC is applicable (Simiyu, 2017).

Pre-Estimation Tests

Unit Root Test

The unit root test is vital to avoid spurious regression which may indicate a relationship among variables which are actually not related. In order to do this, this paper will use the Augmentative Dickey -Fuller (ADF) which is an improvement of the Dickey-Fuller test which assumes that the error term is uncorrelated. It takes the error term as uncorrelated, and addressing the issue by correcting for autocorrelation.as shown below;

$$\Delta X_i = \beta_0 + \beta_1 t + \beta_2 X_{t-1} + \sum_{t-1}^{m} \alpha_i \Delta X_{t-1} + \varepsilon_i \text{……………..eq. (4)}$$

If ε_i is the pure white noise then the null hypothesis stating that $\beta_2 = 0$ thus there is a unit root, and the Akaike information criterion will be used to choose the optimal lag m.

Co-Integration Test

If the results are not spurious, then cointegration may hold. This means that there is a long run relationship between the variables, the chance might be that the linear combination of the nonstationary series is stationary. In order to counter check that this paper will use Johansen approach.

Vector Error Correction Model (VECM)

Prior to running the VECM, the paper employed the Akaike Information Criteria (AIC) and Schwarz Bayesian Information (SBIC) criterion which are among the most popular methods of selecting the optimal lag.

The VECM was adopted on the basis that it is applicable respective of all the variables in the model being integrated at order one I (1) and there is evidence of at least one cointegrating equations which represents a long run relationship among the variables. The Vector Error Correction Model (VECM) is a powerful tool for understanding long-term relationships among integrated variables. A key advantage of the VECM is its ability to model both short-term dynamics and long-term equilibrium relationships simultaneously, provided that the variables are cointegrated, typically requiring them to be of the same integration order, specifically I (1) (Johansen, 1988). This model is particularly useful when dealing with non-stationary time series data that are cointegrated, ensuring that deviations from long-term equilibrium are corrected over time. (Engle and Granger, 1987).

The formulation of the econometric model is constructed by:

$$GHGt = f(GDPC_t, GDPC_t^2, FDI_t, TO_t, EU_t) \ldots\ldots\ldots\ldots \text{eq. (5)}$$

To estimate the VECM long-run equilibrium estimation model, according to Chen & Taylor (2020), is formulated as follows:

$$ECT_t = GHG_t - \beta_1 GDPC_t - \beta_2 GDPC_t^2 - \beta_3 FDI_t - \beta_4 TO_t - \beta_5 EU_t - \alpha 0 \ldots \text{eq. (6)}$$

ECT is the error correction term, GHG is the greenhouse gases emissions, GDPC is the gross domestic product per capital, GDPC squared is the squared form of GDPC, FDI is the foreign direct investment inflows, TO is the trade openness which is the total sum of exports and imports as a percentage of GDP, EU is the total energy use of primary energy before transformation to other end-use fuels. Thereafter, the granger causality test was conducted to test the causal relationship among the variables.

Post Diagnostics Test

The tests conducted included checks for autocorrelation, heteroskedasticity, normality, and stability of the model. Autocorrelation tests were performed to verify that residuals were uncorrelated, ensuring the validity of the model's estimations. The heteroskedasticity test was used to assess the constancy of variance in the residuals, a key assumption for consistent and unbiased parameter estimates. Normality tests were conducted to confirm that the residuals follow a normal distribution, which is crucial for the accuracy of hypothesis testing. Finally, the stability of the model was evaluated to confirm the presence of cointegrating relationships and the appropriate adjustment dynamics within the model.

FINDINGS

This chapter gives a comprehensive presentation and discussion of empirical findings of the study. Table 1 below shows the descriptive statistics results summarizing the key descriptive statistics, including the mean, standard deviation, minimum and maximum values for each variable over the 33 observations in this study.

Table 1: Descriptive Statistics

Variables	Std. Dev	Mean	Minimum	Maximum
Ghg	1.54e+07	7.79e+07	5.57e+07	9.94e+07
Gdpc	515.5347	924.6388	353.8302	1840.321
Gdpcsq	1035629	1112679	125195.8	3386780
Fdi	5.89e+08	6.01e+08	3.43e+07	2.10e+09
To	7.949771	67.88639	56.12138	86.20851
Eu	7.949771	562.9038	308.1278	710.5588

Number of observations = 33

Table 2 shows the unit root test results. The study employed the mostly accepted Augmented Dickey Fuller (ADF) test for stationary to conduct this test due to its ability to handle serial correlation through inclusion of lagged terms and its reliable critical values for hypothesis testing (Dickey & Fuller, 1981). The null hypothesis of the ADF is that a variable has unit root (non-stationary). Hence, when P-value is less than 0.05, the null hypothesis is rejected and concluded that a variable is stationary.

Table 2: Augmented Dickey Fuller Test Results

Variable	At Level	At first Difference	Order of Integration	At Level	At First Difference	Order of Integration
	No Trend & Intercept			With Trend & Intercept		
l_ghg	0.6557	0.0000**	I (1)	0.5625	0.0000**	I (1)
l_gdpc	0.8450	0.0005**	I (1)	0.8494	0.0046**	I (1)
l_gdpcsq	0.8397	0.0005**	I (1)	0.8403	0.0046**	I (1)
l_fdi	0.3359	0.0000**	I (1)	0.6982	0.0000**	I (1)
To	0.1404	0.0000**	I (1)	0.0655	0.0000**	I (1)
l_eu	0.5558	0.0000**	I (1)	0.3432	0.0000**	I (1)

Note: ***. ** And * indicate significance level at 1%, 5% and 10% respectively.

From the ADF results, all the variables are non-stationary at their levels given that the P-values at both scenarios (with or without trend and intercept). However, after differencing the variables once, all variables become stationary as evidenced by the P-values being statistically significant at the 5% level of significance hence all the variables are stationary at order one, I (1). The consistency of the results across both specification (with or without trend and intercept) confirmed these results and justifies the use of differencing to achieve stationarity.

Table 3 shows the correlation test results. The VIF quantifies how much the variance of a regression coefficient is inflated due to collinearity with other predictors. A high VIF i.e. one that is greater than 10 indicates a high degree of multicollinearity, leading to unreliable estimates of regression coefficients (Kutner et al. 2004). Table 3 shows the VIF results for the variables used in this paper.

Table 3: VIF Test Results

Variable	VIF	1/VIF
l_gdpcsq	2079.69	0.000481
l_gdpc	2075.91	0.000482
l_fdi	2.46	0.405701
l_eu	1.84	0.536341
To	1.74	0.573846

Note: if VIF > 10, Indicates high multicollinearity.

From the results above, all the respective VIF for each variable is less than 10 indicating no high collinearity among the variables except for the log of GDP per capita squared (l_gdpcsq) and log of GDP per capita (l_gdpc) are highly correlated given that the former is the squared of the latter.

Table 4 shows the cointegration test results .Cointegration test is important in order to determine whether a set of variables have a long/term equilibrium amongst them. Johansen cointegration test was used based on its ability to provide detailed insights into the long-term relationships and for its robustness in handling multiple variables hence making it ideal for complex economic models (Johansen, 1991). Table 4 shows the results of the Johansen test.

Table 4: Johansen Co-Integration Test Results

Maximum Rank	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	-27.553587	-	118.6843	94.15
1	-9.3173555	0.69165	82.2118	68.52
2	6.9002188	0.64876	49.7766	47.21
3	17.004887	0.47895	29.5673*	29.68
4	24.322737	0.37632	14.9316	15.41
5	30.073481	0.30997	3.4301	3.76

The Johansen cointegration test indicates that there are exactly three cointegrating relationships among the variables because the trace statistic value at rank 3 is lower than the 5% critical value. This suggests that the variables share a stable, long-term relationship that can be modeled effectively with a VECM.

Table 5 shows the optimal lag length selection results. The paper compared results from four lag length criteria which included the Final Predication Error (FPE), Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQIC) and the Schwarz Bayesian Information Criterion (SBIC). The results are as shown below:

Table 5: Optimal Lag Length Selection Results

Lag Order	LL	LR	FPE	AIC	HQIC	SBIC
0	-102.54		7.2E-05	7.48569	7.57429	7.76858
1	-11.8524	181.38	1.80E-06	3.71396	4.33414	5.69418*
2	97.436	36.86	1.00E-06	2.83686	3.98862	6.51441
3	121.75	97.7387	5.80E-07	1.12147*	2.80482*	6.49636
4			-5.1e-37*			

In selecting the optimal lag for the model, the standard econometric practices needed to balance model accuracy and parsimony were followed. The AIC and HQIC suggested using lags (3), which aligned with ensuring that the model captures the underlying dynamics while avoiding overfitting (Hannan & Quinn, 1979; Luetkepohl, 2005). Additionally, according to Liew (2004), the AIC is arguably considered to be more accurate for samples sizes that are less than 60 while HQIC is also considered to provide a middle ground between the AIC and SBIC, making lags (3) a more considerable choice for the model given that the sample size used in this paper is below 60. Although the SBIC suggested lag (1) due to its higher penalty on additional parameters, and the FPE suggested lags (4) for predictive accuracy, the balance achieved by AIC and HQIC was prioritized in this paper.

Table 6 shows the Vector Error Correction Model (VECM) results. The VECM with lags (3) (as concluded from the lag length selection criteria) was the most appropriate model to be used. The long run relationship results are as shown below:

Table 6: VECM Long Run Test Results

	Coef.	Std. Error	t-stats	p-value
l_ghg	1			
l_gdpc	-0.8352	.2646	3.16	0.002**
l_gdpcsq	0.00000131	2.12e-07	-6.16	0.000**
l_fdi	-0.2154	.0960	2.24	0.025**
to	-0.0361	.0109	3.28	0.001**
l_eu	0.4886	.2217	-2.12	0.031**
Cons	-25.9158	4.0198	-6.45	0.000**

Note: *. **. *** denotes significance at 1%, 5% and 10% level of significance respectively

Hence, the cointegration equation is:

l_ghg = -25.9158 + (- 0.8352) l_gdpc + (0.00000131) l_gdpcsq + (- 0.2154) l_fdi + (-0.0361) to + (0.4886) l_eu.

The results from the VECM, all the coefficients are significant at the 5% level of significance. The results show that there exists a negative relationship between the gross domestic product per capita and greenhouse gas emission. The coefficient of -0.8352 indicates that a 1% increase in gross domestic product per capita will decrease greenhouse gas emission by 0.86352%. However, for the square of gross domestic product per capita, there exists a positive relationship between the squared values and greenhouse gas emissions. The coefficient of 0.00000131 indicates that a 1% increase in the squared values will increase greenhouse gas emissions by 0.00000131%. The initial negative relationship and the positive long run relationship implies that an increase in gross domestic product per capita beyond a certain threshold are associated with increases in greenhouse gases emissions in Zambia during the period of 1990 to 2022. Thus, these results depict a U-shaped curve relationship between GDPC which is used as an indicator for economic growth in this study. This is the opposite of the EKC, therefore based on the Vector Error Correction Model, the EKC hypothesis is not supported in Zambia between 1990 and 2022.

The relationship between FDI inflows and greenhouse gases shows a negative long-term relationship with a coefficient of -0.2154. Thus a 1% increase in FDI inflows decreases greenhouse gas emissions by 0.2154%. This relationship does not support the Pollution Haven Hypothesis and supports the Pollution Halo hypothesis. The coefficient of -0.0361 between trade openness and greenhouse gases also reflects a negative long-term relationship between trade openness and greenhouse gases showing that a 1% increase in trade openness will decrease greenhouse gases by 0.0361%. The similar results of the relationship between FDI and trade openness with greenhouse gases in Zambia suggests that an increase in foreign investment and the reduction of trade barriers has a positive impact on the environment as far as greenhouse gas emissions are concerned. The positive coefficient of 0.4886 between total energy use and greenhouse gases reflects that a 1% increase in energy use in Zambia, increases greenhouse gas emissions by 0.4886%.

The short run results of the VECM are shown below:

Table 7: VECM Short Run Test Results

	Coef.	Std. Error	t-stats	p-value
ECT	-.0543	.0542	-1.00	0.317
D_l_ghg	-.2269	-.2363	-.96	0.337
D_l_gdpc	.5162	.1990	2.59	0.010**
D_l_gdpcsq	-1.97e-07	1.08e-07	-1.08	0.069***
D_l_fdi	-.0065	.0239	-0.27	0.785
D_to	.0054	.0028	1.89	0.058***
D_l_eu	.1161	.1135	1.02	0.306
Log likelihood	-397.1895			
AIC	32.0793			
HQIC	33.33442			
SBIC	36.00265			

Note: *. **. *** denotes significance at 1%, 5% and 10% level of significance respectively

The AIC and SBIC values in the short run model are relatively small which indicates the reasonability of the model estimation. The error correction term (ECT) of -0.0543, indicating that about 5.43% of the deviation from the long-run equilibrium is corrected each period. However, this correction is not statistically significant suggesting that deviations from the long-run equilibrium do not have a significant impact on the short-run adjustments in greenhouse gas emissions. The insignificance of the ECT suggests that the speed of adjustment is not strong enough to be statistically significant in this short-Run, this could be to various reasons such as the influence of other short-run dynamics or external factors are not captured in the model as this model focuses on analyzing the long run impacts of economic growth and FDI on greenhouse gases. Other key finding in the short-run dynamics show that there is a significant relationship at 5% level of significance between GDPC and greenhouse gas emissions indicating that a 1% increase in GPDC is associated with a 0.52% increase in greenhouse gas emissions.

Table 8: Diagnostic Tests Results

Problem	Test	p-value
Autocorrelation	Breusch-Godfrey LM	0.2151
	Langrange Multipler (lag 3)	0.2826
Heteroskedasticity	Breusch-Pagan-Godfrey	0.8086
Normality	Doornik-Hansen	0.9256
	Skewness/Kurtosis (Joint)	0.8430

The Breusch-Godfrey test for autocorrelation yielded a P-value of 0.2151 at a lag of 3, and the Lagrange Multiplier test showed P-values of 0.6614, 0.70018, and 0.28269 for lags 1, 2, and 3, respectively. These results indicate no significant evidence of autocorrelation in the residuals. The Breusch-Pagan test for heteroskedasticity returned a P-value of 0.8086, suggesting that the assumption of homoskedasticity holds. Tests for normality, including the Doornik-Hansen test (P-value of 0.9256) and the Skewness/Kurtosis tests (P-values of 0.5798, 0.8517, and 0.8430 for skewness, kurtosis, and joint normality, respectively), confirmed that the residuals are multivariate normally distributed. Overall, these diagnostic results support the validity and robustness of the model by confirming that key assumptions are not violated.

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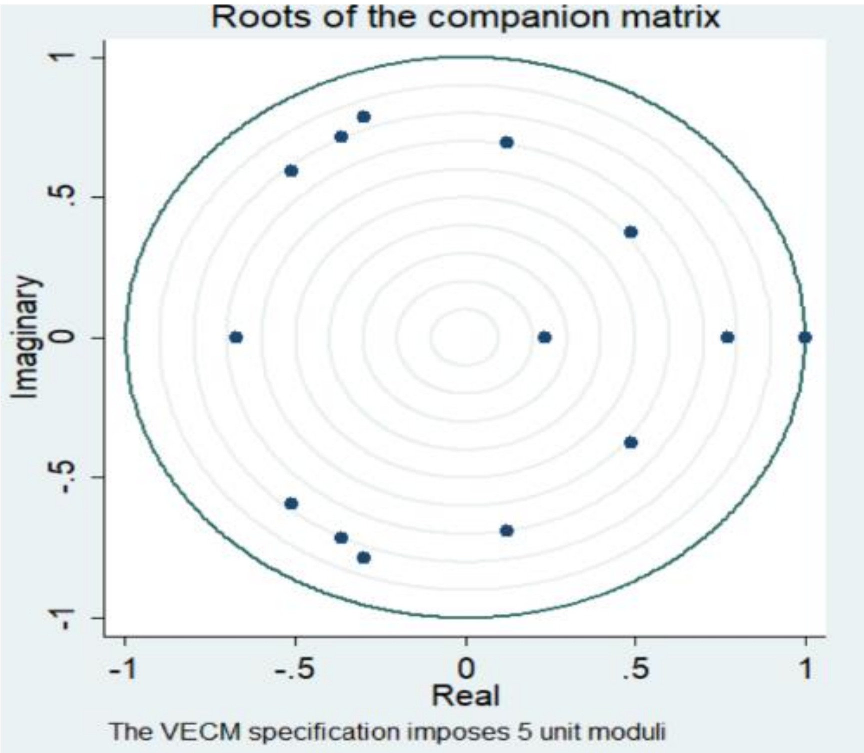
Table 9: Stability Test Results



Eigenvalue stability condition	
Eigenvalue	**Modulus**
1	1
1	1
1	1
1	1
1	1
-.29781 + .7868115i	.841287
-.29781 - .7868115i	.841287

Note: The VECM specification imposes 5-unit moduli

Eigenvalues with a modulus of 1 indicates the presence of cointegration relationships among the variables, which is a desirable property indicating long-term stability and equilibrium. The eigenvalue with a modulus significantly different from 1 (approximately 0.846879) suggests a faster adjustment process for the variables in the model.

Therefore, based on these eigenvalues, the model can be considered stable with respect to the presence of cointegrating relationships and the adjustment dynamics captured by the VECM.

Table 10 shows the Granger Causality test results. In the context of this study, the Granger causality test is employed to explore the directional relationships between greenhouse gas emissions (GHG) and key economic variables, including GDP per capita (GDPC), foreign direct investment (FDI), trade openness (TO), and total energy use (EU). The test examines whether changes in one variable provide statistically significant information for predicting changes in another.

Table 10: Granger Causality Test Results

Null hypothesis: X does not granger cause Y			
Dependent Variable (D_l_ghg)	**chi2**	**p-value**	**Decision**
D_l_gdpc	6.72	0.0095	Reject
D_l_fdi	0.07	0.7846	Fail to reject
D_to	3.59	0.0581	Fail to reject
D_l_eu	1.05	0.3065	Fail to reject

The Granger Causality test results show that GDP per Capita granger causes greenhouse gas emissions with a P-value of 0.0095 which makes the null hypothesis of no granger causality rejected. This indicates that GDPC significantly predicts greenhouse gas emissions. Other variables (FDI, trade openness and total energy use) do not granger because greenhouse gases since their P-values are above 0.05 significance level. The causal relationship between the different other combinations of the variables also shows no granger causality.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study analysed the dynamic relationship between economic growth, foreign direct investment (FDI), and greenhouse gas (GHG) emissions in Zambia from 1990 to 2022, testing the Environmental Kuznets Curve (EKC) and Pollution Haven Hypothesis (PHH). The results from the Vector Error Correction Model (VECM) reveal a U-shaped relationship between GDP per capita and GHG emissions, where economic growth initially reduces emissions but eventually exacerbates environmental degradation as income levels rise. This conclusion was drawn statistically from the statistical U-shaped relationship between GDP per Capita and GHG emissions. This aligns with prior findings that the EKC does not hold in Zambia according to Makondo et al. (2021) and Mudenda (2016). It is also in line with results from relatively similar economics such as Kenya according to the study by Simuyu (2017). The period of study reflects Zambia's economic transitions, with earlier years marked by low emissions due to limited economic activity and later years showing increased emissions from expanded industrial and energy activities driven by growth.

The findings also indicate that the PHH does not statistically hold in Zambia. Instead the results support the PHAH, as FDI inflows are statistically negatively related to GHG emissions. This implies that FDI inflows have contributed positively to environmental sustainability of the country. This aligns with Abdouli et al. (2018), who found that FDI reduces carbon emissions in the BRICTS countries. A possible explanation for the statistical acceptance of the PHAH in Zambia lies in the country`s increasing efforts to integrate green growth considerations into its development agenda. The country has committed to formulating an inclusive Green Growth Strategy to ensure that natural resource management, polluting control, and the climate resilience are central to its path towards becoming a middle-income country by 2030. These efforts, supported by international development cooperation since 2004, aim to align growth with environmental sustainability and suggest that FDI entering Zambia is often tied to sectors governed by stricter environmental regulations such as green and renewable energy thus encouraging cleaner technologies and responsible business practices (Casado-Asensio et al., 2014). Additionally, most of the Zambia's international initiatives have been supported by international development partners, who provide finance, knowledge transfer, and capacity building (Watson et al., 2013).

Recommendations

To ensure that Zambia maintains a sustainable growth trajectory while addressing environmental degradation, it is important to continue strengthening regulatory measures in high emission sectors particularly mining, agriculture and mining. Despite the statistical evidence that FDI in Zambia contributes positively to environmental sustainability supporting the PHAH, weak regulatory enforcement poses significant risks in changing this course. For example, the recent discharge of 50 million litres of toxic waste into Kafue River from a Chinese owned mine in Chingola highlights gaps in institutional capacity and accountability of foreign investors (Associated Press, 2025).

Therefore, strengthening Environmental Impact Assessment (EIAs), increasing inspection frequency, and imposing penalties for both non-compliant foreign and local investors are highly recommended. This recommendation is highly important considering that statistical evidence showed the nonexistence of EKC showing a U-shaped curve relationship between GDP per Capita and GHG emissions. However, effective implementation is highly constrained by limited financial funding and relatively low budget allocations towards environmental protection. The capacity of key regulatory agencies such as Zambia Environmental Management Agency (ZEMA) and Mines Safety Department (MSD) remain very limited despite modestly improvements in technology and human resource over the past years. Additionally, the EIAs process remains largely ineffective due to weak stakeholder engagement, poor public consultations, and inadequate quality of EIA reports (Makondo 2015).

The country should enhance policies that attract and retain environmentally responsible FDI inflows which offer incentives for clean technologies, particularly in renewable energy and green infrastructure. It is important to note that Zambia's experience with donor supported environmental programs provides a strong foundation for implementing a comprehensive inclusive Green Growth Strategy which includes measurements, reporting and verification system aligned with Nationally Determined Contribution (NDCs) which targets emissions reductions (Government of Zambia, 2021). Theses policies reforms if well implemented and supported can potentially reconcile economic growth and balance with environmental protection.

Conflict of Interest:

The authors declare no conflict of interest.

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