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An Empirical Investigation of the Pollution Haven-Halo Nexus in Eastern and Southern Africa

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Abstract: This study looks into the relationship between trade and pollution in Eastern and Southern Africa from 1977 to 2016. This timeframe is particularly relevant as it was marked by rising CO_2 emissions despite major climate agreements such as the Kyoto Protocol (1997), Reducing Emissions from Deforestation and Forest Degradation (REDD+, 2007), as well as the Paris Agreement (2015). Using time-series data and the Fully Modified Least Squares (FMOLS) method, the analysis tests the Pollution Halo and Pollution Haven Hypotheses with CO_2 emissions as the regressand while trade openness, agricultural expansion, Foreign Direct Investment (FDI) and structural breaks are independent variables. Findings indicate that trade openness significantly raises CO_2 emissions, with a coefficient of 5632.72 kilotonnes ($p<0.01$), supporting the Pollution Haven Hypothesis. Agricultural expansion has an even more pronounced impact, with a coefficient of 60329.08 kilotonnes ($p<0.01$), aligning with the Heckscher-Ohlin (H-O) model, which posits that land-rich countries tend to specialize in land intensive sectors. FDI, however, exhibits a negative but statistically insignificant relationship with emissions (coefficient = -4190.02, p = 0.5531), thus offering limited evidence for either the Pollution Haven or Pollution Halo Hypothesis in this context. The structural break variable (BREAKS), included to account for major policy or economic shifts, also has a strong and significant positive effect (coefficient = 130888.9, $p<0.01$), indicating that such shifts contributed to higher emissions. The model explains approximately 94% of the variation in emissions ($R^2 = 0.9413$), underscoring the robust explanatory power of the included variables. These findings highlight the environmental risks of trade-driven agricultural expansion and emphasize the urgent need for stronger environmental regulation, sustainable agriculture practices, green trade and FDI policies, and regional collaboration, including the implementation of carbon pricing. The study calls for further research into the quality of institutional frameworks, the specific characteristics of FDI, and sector-specific environmental impacts to inform more targeted and sustainable policy interventions.

Keywords: Carbon Dioxide, Trade Openness, Pollution Halo Hypothesis, Pollution Haven Hypothesis

Introduction

Trade, defined simply as the exchange of goods and services is an integral aspect of the economy that is closely linked to environmental outcomes. A simple example to illustrate this is a small shop selling sweets which may generate profit for the seller and utility for the consumer, but the resulting waste, such as plastic wrappers discarded along the street, contributes to pollution. This basic scenario reflects a broader issue in the global landscape, where large-scale trade in manufactured goods, machinery, fossil fuels, and medicines often leads to more significant environmental concerns. Additionally, trade-related specialization, where countries focus on industries in which they have a comparative advantage, can

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exacerbate localized environmental problems, concentrate pollution and create critical issues in specific regions.

Environmental degradation is further compounded by population growth, which increases demand for food, housing, and energy. This expansion leads to deforestation and other environmental stresses as countries make space for agricultural production, infrastructure, and energy consumption. These dynamics highlight the need for a better comprehension of how economic activity, especially trade, affects the environment. The study thus aims to explore how trade influences the environment and the mediating role of agriculture in this process.

International Agreements

Major international climate agreements, such as the United Nations Framework Convention on Climate Change (UNFCCC) and subsequent pacts like the Kyoto Protocol (1997), REDD+ (2007), and the Paris Agreement (2015), reflect a collective recognition of the environmental challenges posed by economic activities. Despite these international commitments, data from East and Southern Africa shows rising carbon dioxide emissions from 1977 to 2016 as shown in Figure 1, highlighting the continued environmental impact of trade.

A central tenet of the Sustainable Development Goals (SDGs) is ensuring that trade does not undermine the environment. SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) explicitly call for action to reduce the environmental footprint of global trade as part of responsible consumption and climate efforts (United Nations Conference on Trade and Development, 2022).

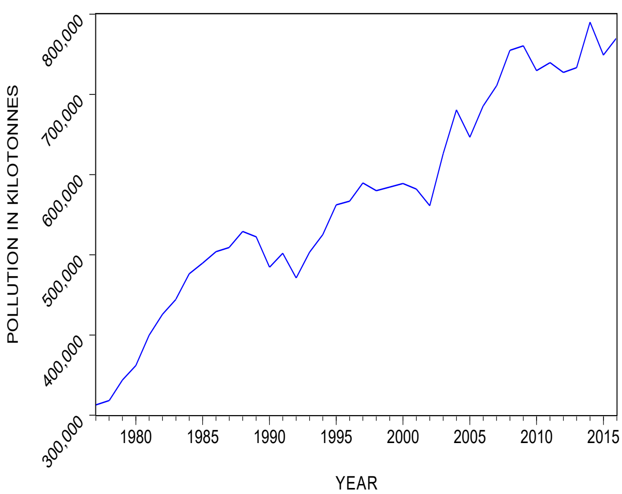

Fig. 1: Pollution Emissions from Solid, Liquid and Gaseous Fuel consumption for East and Southern Africa (Source: World Bank, World Development Indicators)

Trade liberalization, particularly in developing regions with weaker regulatory frameworks, can increase CO_2 emissions and hinder climate change mitigation efforts (Managi *et al*., 2008). Furthermore, Millennium Development Goals (MDG) number 7 on Environmental Sustainability also stresses the importance of integrating environmental considerations into development policies, as demonstrated by studies in Zambia (Nakata *et al*., 2022; Mwaanga *et al*., 2019).

Aim of the Study

This study seeks to answer the central question of how international trade influences carbon dioxide (CO_2) emissions in Eastern and Southern Africa, and the mediating role of agriculture in this relationship. In line with this question, the study tests two key hypotheses grounded in existing environmental and trade theories.

Consistent with the Pollution Haven Hypothesis (PHH), Hypothesis 1 (H_1) suggests that when environmental regulations are weak, greater trade openness leads to an increase in CO_2 emissions. Hypothesis 2 (H_2) proposes that trade openness can reduce CO_2 emissions by facilitating the transfer of cleaner technologies and practices, consistent with the Pollution Halo Hypothesis (PHoH).

Literature Review

Theoretical Review

The dynamic linking trade and environmental degradation is highly complex, leading various hypotheses to offer differing viewpoints. According to the Pollution Haven Hypothesis (PHH), weaker environmental standards encourage "dirty" industries to relocate, thereby concentrating and increasing pollution emissions in those host countries (Harris and Roach, 2013; Tietenberg and Lewis, 2018). This theory argues that trade liberalization can shift carbon-intensive production to these “haven” regions, thus leading to overall increase in global emissions. In contrast, the Pollution Halo Hypothesis (PHoH) maintains that the presence of multinational firms improves the host country environments by transferring cleaner and environmentally superior technologies that contribute to lowering of emissions in the countries they operate (Bento *et al*., 2019; Shunsuke *et al*., 2008).

The Factor Endowment Theory posits that comparative advantage dictates national specialisation in industries that use locally abundant factors intensively. (Salvatore, 2013). Similarly, Carbon Leakage Theory highlights that firms may relocate to regions with laxer emissions policies, thereby increasing global emissions (Perman *et al*., 2003). The Porter Hypothesis on the other hand challenges the notion that environmental regulations are burdensome, suggesting that stringent regulations can

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drive innovation, thereby reducing emissions over time (Harris and Roach, 2013).

The Environmental Kuznets Curve (EKC) hypothesis postulates a non-linear, inverted U-shaped trajectory for environmental degradation, where economic growth initially increases emissions but later leads to improvements (Perman *et al*., 2003). Trade may either exacerbate or mitigate emissions depending on a country's state of development, or position on the curve.

Empirical Review

The empirical literature examining the pollution halo hypothesis (PHoH) and the pollution haven hypothesis reveals a multifaceted dynamic between trade, foreign investment (FDI), and environmental degradation, with findings varying significantly across regions and contexts.

Studies from Africa

Studies focusing on Zambia highlight the environmental challenges posed by mining activities, where lead contamination (Nakata *et al*., 2022) and air pollution (Mwaanga *et al*., 2019) are prevalent, yet these studies often lack explicit analysis of how Zambia's economic policies and enforcement of environmental standards contribute to these issues (Cuthbert *et al*., 2021; Mudenda, 2016; Osei-Hwedie, 1996). Broader African studies (Bouzhahzah, 2022; Dauda *et al*., 2021; Tenaw, 2020; Tiba and Belaïd, 2020) provide a more generalized view, demonstrating that while trade openness can attract pollution-intensive industries, innovation and strong institutions can mitigate these effects, though the specific mechanisms and sectoral impacts require further investigation. Country-specific studies in South Africa by Udeagha and Ngepah (2022), in Cote d'Ivoire by Assamoi *et al*. (2020), and in Ghana by Solarin *et al*. (2017) reinforce the PHH, showing that increased FDI often leads to environmental degradation, but also suggest that factors like technological advancements and institutional quality can influence outcomes.

Studies from Asia

In Asia, research indicates a complex interplay of factors, with studies on China by Ozkan *et al*. (2023); Bashir (2022); Zheng *et al*. (2022); Sun *et al*. (2017), as well as studies from Pakistan by Nadeem *et al*. (2020); Ur Rahman *et al*. (2019) largely confirming the PHH, where FDI contributes toward increased emissions due to weak regulations. However, studies in India (Bagchi and Sahu, 2025; Dietzenbacher and Mukhopadhyay, 2007), Indonesia, and Korea (Bulus and Koc, 2021) reveal a more nuanced picture, with evidence of the pollution halo effect, where FDI enables the adoption of greener technologies and sustainable practices. The research papers highlight the significance of distinguishing between different types of FDI and considering the impact of varying regulatory environments.

Studies from Europe and The West

A substantial body of Western and European empirical evidence (Bekun *et al*., 2023; Bulut *et al*., 2021; Cil, 2023; De Beule *et al*., 2022; Levinson and Taylor, 2008; Marconi, 2012; Martínez-Zarzoso *et al*., 2017; Millimet and Roy, 2016; Tachie *et al*., 2020; Wagner and Timmins, 2009) points to mixed findings concerning environmental outcomes., with some evidence of the PHH, particularly in specific industries and under certain regulatory frameworks, but also highlight the importance of stringent environmental regulations in stimulating innovation as well as promoting cleaner production practices.

Cross-Continental Studies

Cross-continental studies (Ali and Wang, 2024; Eke Balla and Kounagbè Lokonon, 2024; Ozcelik *et al*., 2024; Li *et al*., 2022; Musah *et al*., 2022; Benzerrouk *et al*., 2021; Balsalobre-Lorente *et al*., 2019; Destek and Okumus, 2019; Tang, 2015; Grether *et al*., 2012; MacDermott, 2009; Cole, 2004) further emphasize the importance of institutional quality, regulatory enforcement, and policy frameworks in shaping environmental outcomes. These studies also highlight the need for more granular analyses of sector-specific impacts, temporal dynamics, and the mechanisms through which FDI and trade influence environmental quality, calling for further research to address existing gaps and refine understanding of these critical relationships. They also highlight the need to analyse the role of global value chains, and how they contribute to pollution transfer.

Thematic Analysis

From the literature reviewed, it is observed that thematic differences across the regions reveal how varying institutional, regulatory, and economic contexts shape the nexus between trade, foreign investment, and environmental degradation.

The dominant theme in Africa centres on weak environmental governance and sector-specific vulnerabilities, particularly in mining and extractive industries. These studies largely support the Haven Hypothesis (PHH), but they also highlight a gap in analysing how local institutions mediate environmental outcomes.

In Asia, the literature presents a dual narrative: While studies in countries like China and Pakistan confirm PHH due to weak enforcement, others from India, Indonesia, and Korea reflect a Pollution Halo dynamic, suggesting that technological transfer and regulatory evolution can foster cleaner practices. This region emphasizes the importance of FDI composition and sector-specific effects. In contrast, European and Western studies underscore the role of strong regulatory frameworks and institutional maturity, which often lead to cleaner production through innovation, thereby lending support to the Porter Hypothesis and, in some cases, the halo effect.

Cross-continental research adds a broader layer by stressing institutional quality and global policy architecture as pivotal mediators of environmental outcomes, advocating for granular, sector-specific, and temporal analyses. These thematic distinctions illustrate that while the PHH may manifest more clearly in developing contexts with regulatory gaps, the Pollution Halo effect tends to emerge in environments where policy, regulation, and institutional enforcement support sustainable investment and innovation.

Materials and Methods

Employing a quantitative, time-series research design, this study investigates the validity of the Pollution Halo and Haven Hypotheses within Eastern and Southern Africa, a region characterized by increasing trade, foreign investment, and significant agricultural activity, which often leads to deforestation. The selection of this region is justified by its dynamic economic landscape, as highlighted by the United Nations Conference on Trade and Development (2002), which notes substantial increases in FDI inflows to countries like Ethiopia, Uganda, and Tanzania. The increase in FDI across regional groupings, including the Common Market for Eastern and Southern Africa (COMESA), the East African Community (EAC), and the Southern African Development Community (SADC) further underscores the relevance of this study. The region's heavy reliance on agriculture, as emphasized by AICCRA (2004), which contributes to deforestation and is vulnerable to climate change, makes the region an ideal setting to explore the interplay between economic development and environmental sustainability.

Data Sources

This research utilizes 40 years of time-series data, spanning 1977 through 2016. All the data was acquired from the World Bank Database, and more specifically the World Development Indicators, a reliable repository of macroeconomic and environmental indicators. The study utilizes annual observations for the selected variables, encompassing the entire available dataset within the specified timeframe for the 26 countries in Eastern and Southern Africa. Thus, secondary data sampling is applied, as the study uses available data covering the region's economic and environmental dynamics.

Variable Definitions and Measurement

The study utilizes several key variables to investigate the dynamics between investment, trade, agriculture, and environmental degradation. The dependent variable, Carbon Dioxide Emissions (CO2SLG), is used as a proxy for environmental degradation, measured in kilotonnes (kt). This variable is calculated as the sum of CO_2 emissions from solid, liquid, and gaseous fuel consumption, reflecting the impact of fossil fuel usage and industrial processes on greenhouse gas emissions. The independent variables include.

Trade Openness (TRADE): Measured as the ratio of total trade volume (imports + exports) to Gross Domestic Product (GDP), expressed as a percentage. These variable measures the degree to which an economy is integrated into global trade networks.

Foreign Direct Investment (FDI): This variable quantifies net FDI inflows as a percentage of GDP to reflect the influence of foreign capital on the recipient economy.

Deforestation (AGRIC): Represented by agricultural land as a percentage of total land area. This variable serves as a proxy for deforestation, reflecting the environmental impact of agricultural expansion, especially relevant in Eastern and Southern Africa.

Pre-Estimation Tests

The study employs a rigorous econometric methodology to probe the time-series data and test the hypotheses. Pre-estimation tests are conducted to ensure the data's suitability for econometric analysis.

Stationarity Tests (Unit Root Tests): To establish the order of integration for each variable and ensure their stationarity, the Augmented Dickey-Fuller (ADF) test is applied. Failing to correct for non-stationary data can result in spurious regressions and unreliable statistical inferences as highlighted by Enders (2015).

Structural Breakpoint Test: The Quandt-Andrews Breakpoint Test is used to detect structural breaks in time-varying relationships between variables. As highlighted by Greene (2003); Enders (2015), this test is crucial for detecting changes in the underlying relationships between variables.

Cointegration tests are performed to identify long-term equilibrium relationships between the variables.

Johansen System Cointegration Test: As detailed by Greene (2003), this procedure determines the cointegrating vector count, which serves as an indicator of long-run relationships.

Engle-Granger Cointegration Test: Gujarati and Porter (2009) explain how this test employs Fully-Modified OLS (FMOLS) and an ADF test of the residuals to evaluate whether the variables follow a shared long-term trajectory.

Granger causality tests are used to explore predictive relationships between the variables, determining whether past values of one variable can predict another, as explained by Enders (2015).

Model Specification

At the heart of this study is the Fully-Modified Ordinary Least Squares (FMOLS) model. By adjusting for both endogeneity bias and autocorrelation, FMOLS delivers consistent and dependable estimates of the long-run equilibrium relationships. The equation for this model is:

$$CO2SLG_t = \beta_0 + \beta_1 TRADE_t + \beta_2 FDI_t + \beta_3 AGRIC_t + u_t \quad (1)$$

Where $CO2SLG$ is the dependent variable, $TRADE, FDI$ and $AGRIC$ are the independent variables, β_0 is the intercept term, $\beta_1, \beta_2, \beta_3$ represent coefficients of the independent variables and u_t is the error term, while the FMOLS estimator after adjusting the coefficient estimates for the long-run covariance structure is:

$$\hat{\theta}_{FMOLS} = (\textstyle\sum_{t=1}^{T} Z_t Z_t')^{-1} \left(\sum_{t=1}^{T} Z_t y_t^{+} - T \begin{bmatrix} \hat{\lambda}_{12}^{+\prime} \\ 0 \end{bmatrix} \right) \quad (2)$$

Where $\hat{\theta}$ is the vector of cointegrated parameters (including $\beta_1, \beta_2, \beta_3$), $Z_t = (X_t', D_t')$ is the vector of regressors, including the deterministic trend where applicable, Z_t' is the transpose of Z_t, y_t^{+} represents the dependent variable after bias correction and $\hat{\lambda}_{12}^{+\prime}$ is the bias-corrected value of the cointegrating parameter. In this corrected model, the estimates (i.e. $\hat{\beta}_1, \hat{\beta}_2, \hat{\beta}_3$) represent the underlying long-term connections linking the CO_2 dependent variable to the independent variables, while effectively managing the issues of serial correlation and endogeneity among the regressors. This method is supported by the works of Phillips and Hansen (1990) and Hansen (1992).

Post-Estimation Tests

Post-estimation diagnostic tests are conducted to verify the model's robustness.

Serial Correlation Test (ACF and PACF): Following the methodology outlined by Greene (2003); Gujarati and Porter (2009), the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) are critical tools used for diagnosing serial correlation within the residual series.

Normality Test (Jarque-Bera Test): This test verifies whether the residuals portray a normal distribution, a crucial characteristic for the validity of hypothesis tests as discussed by Gujarati and Porter (2009).

Multicollinearity Test (Variance Inflation Factor - VIF): This test assesses the extent of multicollinearity among the regressors, as outlined by Gujarati and Porter (2009).

Model Fit: The coefficient of determination (r^2) is used to assess the goodness of fit of the model, quantifying how far the model goes in explaining the variability in the regressand, as described by Gujarati and Porter (2009).

Ramsey Regression Specification Error Test (RESET): As detailed by Verbeek (2004), the purpose of this test is to detect errors in the model's structure such as missing variables or an inappropriate functional relationship.

Cumulative Sum of Squares (CUSUMSQ) Test: This test detects changes in the model's parameters over time, indicating model stability, as outlined by Brown *et al.* (1975).

This robust methodology aims to deliver key insights into the dynamics of trade, FDI, agriculture, and environmental dynamics in East and Southern Africa.

Results

The East and Southern African region comprises of 26 countries, which are rich in natural resources, and home to 60% of Africa's population (World Bank, 2024). The region, characterized by its reliance on agriculture and mining for income and exports, presents a convincing case for studying the interplay between economic activities and environmental degradation.

Study Area and Data Collection

The study area encompasses 15 East African and 11 Southern African countries, exhibiting significant geographic, cultural, and economic diversity. The countries in East Africa include Kenya, Tanzania, Uganda, Rwanda, Burundi, Ethiopia, Somalia, Sudan, South Sudan, Djibouti, Eritrea, Mauritius, Madagascar, Seychelles and Comoros. Those in Southern Africa include South Africa, Namibia, Botswana, Zimbabwe, Mozambique, Angola, Zambia, Malawi, Lesotho, Eswatini (formerly Swaziland) and the Democratic Republic of Congo (DRC). Despite its potential, the region faces challenges such as limited digital connectivity, which programs like the World Bank's IDEA initiative aim to address. The major export and income-generating ventures include agriculture, mining, oil and gas, textiles, tourism, and port services. Data collected from the World Bank, covering the period 1977 to 2016, includes the variables CO_2 emissions (CO2SLG), Agricultural Land Usage (AGRIC), Foreign Direct Investment (FDI), and trade openness (TRADE). Descriptive statistics reveal that CO2SLG is relatively normally distributed, while AGRIC, FDI, and TRADE exhibit positive skewness. The Jarque-Bera test does not reject the null hypothesis of normality for any of the variables.

Table 1, shows descriptive statistics for the four variables: CO2SLG, AGRIC, FDI, and TRADE, each with 40 observations. The Skewness values (ranging from -0.0955 to 0.6430) indicate that all distributions are relatively symmetrical. Kurtosis values (between 1.9162 and 2.7108) suggest that all distributions are flatter than a normal distribution (platykurtic). Crucially, the high Probability values (0.5114 for CO2SLG, 0.3183 for AGRIC, 0.2350 for FDI, and 0.4019 for TRADE) from the Jarque-Bera test all indicate that the variables are normally distributed.

Table 1: Descriptive Statistics

PROPERTY	CO2SLG	AGRIC	FDI	TRADE
Skewness	-0.0955	0.2229	0.6430	0.4372
Kurtosis	2.1235	1.9162	2.7108	2.4264
Jarque-Bera	1.3411	2.2889	2.8961	1.8229
Probability (Jarque-Bera)	0.5114	0.3183	0.2350	0.4019
Observations	40	40	40	40

Pre-Estimation Tests

Several pre-estimation tests were conducted to ensure reliability of the econometric analysis. The ADF unit root tests concluded that every variable was I (1). This means that while the variables contain a unit root at their levels, their first differences are stationary. The Quandt-Andrews breakpoint test initially revealed a significant structural break in 1983 (Max LR F-statistic = 13.01063, p<0.01), necessitating the inclusion of a dummy variable to account for this break. After incorporating the dummy variable, the breakpoint test showed no significant structural breaks (Max LR F-statistic=3.361548, p = 0.1333), indicating model stability. Cointegration tests, using both the Johansen and Engle-Granger methods, validated the existence of long-term equilibrium relationships between the variables (Engle-Granger z-statistic = -30.98340, p = 0.0274). Granger causality tests revealed that CO_2 emissions Granger-cause both AGRIC and FDI (F = 13.9010 p = 0.0007 and F = 7.52643 p = 0.0094, respectively), while TRADE Granger-causes CO_2 emissions (F = 4.88194, p = 0.0336).

Model Specification and Results

Application of the FMOLS model in this study revealed the existence of significant long-run relationships between the chosen variables and carbon emissions. Specifically, agricultural land use (AGRIC) and trade both exhibited highly significant positive impacts on CO_2 emissions (coefficients of 60329.08 kilotonnes and 5632.719 kilotonnes, respectively, with p-values of 0.0000), supporting the pollution haven hypothesis. Conversely, Foreign Direct Investment (FDI) showed a negative but statistically insignificant coefficient (−4190.023, p = 0.5531), offering weak support for the pollution halo hypothesis. Furthermore, structural breaks (BREAKS) were found to significantly increase CO_2 emissions (130888.9, p = 0.0000), underscoring the role of external shocks. The model's robust R-squared value of 0.941, with an adjusted R-squared of 0.934382, indicates that these independent variables collectively explain over 93% of the variation in carbon dioxide emissions. Table 2 illustrates these findings.

Table 2: Regression Results: Regressand - Carbon Dioxide, Method - Fully Modified Least Squares (FMOLS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
AGRIC	60329.08	10195.82	5.917038	0.0000***
FDI	-4190.023	6994.601	-0.599037	0.5531
TRADE	5632.719	1042.925	5.400887	0.0000***
BREAKS	130888.9	20369.39	6.425765	0.0000***
C	-2513875	405173.1	-6.204447	0.0000***
R-squared	0.941289			
Adjusted R-squared	0.934382			

***significant at 1%, **significant at 5%, *significant at 10%

Residual Diagnostic Tests

Tests were conducted on the residuals to validate the model's robustness. The tests for serial correlation (PACF and ACF) showed no significant autocorrelation, suggesting stationarity of the time series. The Jarque-Bera test confirmed that the residuals approximate normality (JB=3.455710, p=0.177665), supporting the model's assumptions. Variance inflation factor (VIF) estimates showed low multicollinearity of between 1.9 and 4.7 among the predictor variables. The RESET test indicated that the model had no specification errors (t = 0.697698, F = 0.486782, p = 0.4901), with no evidence of omitted variable bias or incorrect functional form. The Cumulative Sum of Squares (CUSUMSQ) test results further indicate that the model is stable over time, as the cumulative sum of squared residuals remained within the 5% significance bounds. This suggests that the estimated parameters are consistent and do not exhibit structural instability, as illustrated in Figure 2.

The results from this study provide strong support for the Pollution Haven Hypothesis (PHH) in Eastern and Southern Africa, with agricultural expansion and trade openness significantly contributing to increased CO_2 emissions.

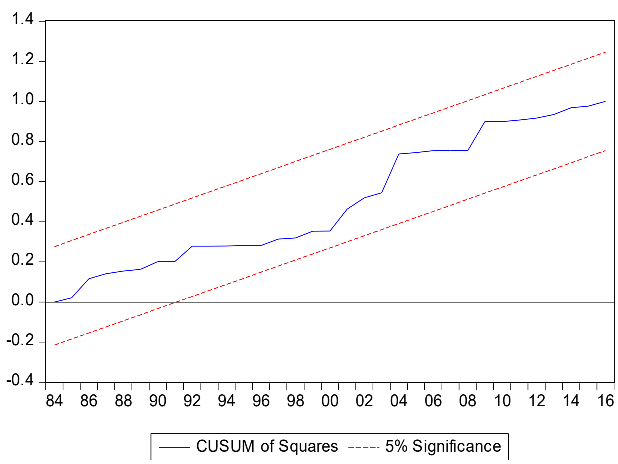

Fig. 2: Cumulative Sum of Squares Test

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Interpretation and Conclusions

The weak evidence for the Pollution Halo Hypothesis indicates that FDI has not significantly contributed to the uptake of greener technologies in the region. The study highlights the intricate interplay between environmental factors and economic activities, emphasizing the influence of CO_2 emissions on agriculture and investment. The results underscore the need for careful policy consideration to mitigate environmental degradation while promoting sustainable economic development in the region.

Discussion

The study gives a comprehensive exploration of the relationship between trade, investment, agriculture, and CO_2 emissions in East and Southern Africa, drawing upon established environmental economics theories and comparing findings with empirical evidence from other regions.

Theoretical Discussion

The study's finding that increased trade openness leads to higher CO_2 emissions strongly corroborates the Pollution Haven Hypothesis (PHH). This hypothesis suggests that industries prone to pollution relocate to areas with weaker environmental laws (Tietenberg and Lewis, 2018; Harris and Roach, 2013). The observed increase in emissions with trade openness suggests that East and Southern Africa may be serving as a "pollution haven" for such activities. However, the absence of a significant direct effect of FDI on emissions adds nuance to the findings. This finding challenges the conventional PHH assumption that FDI is inherently pollution-intensive, indicating that factors such as industry composition or host country-specific regulations may play a moderating role.

The lack of a significant direct impact of FDI on CO_2 emissions means the study neither definitely confirms nor refutes the Pollution Halo Hypothesis (PHoH), which claims FDI promotes transfer of green technology and subsequent reduction in emissions (Bento *et al*., 2019; Shunsuke *et al*., 2008). This neutral finding suggests that FDI inflows are not necessarily increasing emissions, potentially because associated technology transfers are offsetting potential pollution impacts. This might be the case even without explicitly stringent regulatory frameworks, as the inherent nature of FDI or market forces could drive the adoption of more efficient technologies. Further research, however, would be needed to substantiate this claim in future studies.

The Factor Endowment Theory, particularly the Heckscher-Ohlin model, is reflected in the significant influence of agricultural land use on emissions. As resource-rich countries specialize in agriculture due to their abundant land, the agricultural expansion will frequently involve deforestation for new farmland and increased use of mechanized farming techniques, both of which directly contribute to higher CO_2 emissions (Salvatore, 2013). This finding highlights how trade, by encouraging resource-based specialization, can exacerbate environmental impacts in countries focusing on land-intensive sectors like agriculture.

The study thus offers strong empirical evidence supporting both the Pollution Haven Hypothesis and the Factor Endowment Theory, highlighting the significant contributions of trade openness and agriculture to CO_2 emissions in East and Southern Africa. While the Pollution Halo Hypothesis and Porter Hypothesis offer potential explanations, their assumptions are less directly supported. The findings underscore the interconnectedness of trade, agriculture, and emissions, and the importance of considering structural breaks and causality in understanding the environmental impacts of economic activities.

Empirical Comparisons

Zambia

The study's findings on trade openness and emissions align with observations from Zambia, where lenient regulations in the mining sector have allowed for increased pollution (Mwaanga *et al*., 2019). Similarly, the lack of evidence for the Pollution Halo Hypothesis in this regional study is consistent with findings in Zambia, where FDI has not demonstrably introduced environmentally beneficial technologies (Mudenda, 2016; Nakata *et al*., 2022). The observed increase in emissions with trade and agriculture, without a turning point, also mirrors the Zambian context, where economic growth has exacerbated emissions (Cuthbert *et al*., 2021). The absence of a pollution-reducing effect from trade and FDI in the regional study is consistent with Zambia's experience, where economic priorities often overshadow environmental considerations (Osei-Hwedie, 1996).

Africa

This study's findings that trade openness increases emissions aligns with the trend observed in Africa, where trade is thought to draw in polluting industries (Dauda *et al*., 2021). The non-significance of FDI on emissions is consistent with studies showing limited evidence for both the PHH and PHoH in Africa (Tenaw, 2020), although institutional quality can influence FDI's environmental impact (Bouzhahzah, 2022). The link between agricultural land use and emissions is supported by findings from Côte d'Ivoire (Assamoi *et al*., 2020). The study's finding of a one-way causality from trade to emissions contrasts with findings of bidirectional causality in other African contexts (Tiba and Belaïd, 2020), highlighting regional differences. The significance of the 1983 structural break aligns with

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studies that account for historical economic and policy shifts (Assamoi *et al*., 2020), though this study primarily uses it for model stability.

Asia

The positive link between trade openness and emissions is consistent with findings from ASEAN-5 countries (Guzel and Okumus, 2020). However, the lack of a direct, significant link between FDI and emissions contrasts with Asian studies, where FDI frequently corresponds to elevated emissions due to the region's lax regulations (Abdo *et al*., 2020; Sun *et al*., 2017). The structural breakpoint in 1983 aligns with EKC patterns observed in Asian economies (Ozkan *et al*., 2023; Ur Rahman *et al*., 2019), although this study emphasizes agriculture and trade as long-term drivers. The mixed findings on FDI's environmental impact highlight regional differences, with Asian studies showing both PHH and PHoH effects (Abbasi *et al*., 2023), unlike the study's findings in Africa.

The West

The study's findings on trade openness and agricultural land use resonate with European findings on the PHH and PHoH, albeit with regional differences. Stringent regulations in Europe have limited the PHH effect (Martínez-Zarzoso *et al*., 2017), unlike the findings in East and Southern Africa. The emissions surge post-1983 reflects regional economic transitions, similar to findings on carbon leakage in Europe (De Beule *et al*., 2022). Unlike findings in Turkey (Cil, 2023), this study shows no direct link between FDI and emissions. The study's findings partially align with EU findings on trade openness and the EKC (Tachie *et al*., 2020), but the absence of strong evidence for emissions reduction highlights the need for tailored policies.

Cross-Continental

The study's findings echo those from newly industrialized nations, where FDI can have a U-shaped relationship with environmental degradation (Destek and Okumus, 2019). However, the study identifies agriculture and trade as significant factors, rather than energy consumption. The lack of direct evidence linking FDI to emissions contrasts with findings on FDI-driven deforestation in developing countries (Eke Balla and Kounagbè Lokonon, 2024). The context-dependent outcomes of FDI (Ozcelik *et al*., 2024) align with the study's findings, suggesting limited benefits of FDI in driving cleaner technologies in East and Southern Africa. The study's finding on trade openness aligns with findings that trade increases emissions in developing countries (Musah *et al*., 2022; Benzerrouk *et al*., 2021). The structural break may reflect policy shifts (Cole, 2004; Grether *et al*., 2012), but the absence of emissions-reducing effects highlights the need for proactive policies.

Summary

The study successfully achieved its primary goal of analysing the relationships between trade openness, agriculture and CO_2 emissions. The results confirm significant long-term associations, clearly showing that both expanded trade and agricultural activity are key drivers of emissions. The identification of the 1983 structural break underscores the role of economic policies

Conclusion

This study of Eastern and Southern Africa reveals a strong relationship between economic activity and environmental degradation, supporting the Pollution Haven Hypothesis. To mitigate this, a multi-pronged approach is necessary, focusing on strengthened environmental regulations, sustainable agriculture, leveraging trade and FDI, and enhanced regional collaboration.

Recommendations

Firstly, robust environmental regulations are crucial. SADC and COMESA should develop region-wide standards for key industries, mandate environmental audits for FDI, and implement carbon pricing mechanisms. These measures aim to internalize environmental costs and incentivize cleaner production, addressing the policy gap of weak regulations.

Secondly, promoting sustainable agriculture is vital. Given the link between agricultural expansion and deforestation, techniques like agroforestry and conservation tillage should be prioritized. Regional initiatives like REDD+ should be scaled up, and climate-smart agriculture practices should be encouraged. This addresses the policy gap concerning unsustainable agricultural practices and promotes efficient land use.

Thirdly, trade and FDI must be leveraged for sustainability. Green clauses in trade agreements and incentives for sustainable FDI, such as tax breaks and subsidies, can drive the adoption of cleaner technologies. Facilitating technology transfer through partnerships between foreign and local firms is also essential. This aligns with the Pollution Halo Hypothesis and encourages sustainable investments.

Fourthly, regional collaboration and policy harmonization are critical. A regional environmental monitoring system, a unified climate change strategy, and public awareness campaigns can enhance policy effectiveness. Capacity-building for local authorities and public-private partnerships can strengthen institutional capacity. Implementing a regional carbon market and promoting low-carbon infrastructure can incentivize emissions reduction and support green growth. This addresses the need for coordinated regional efforts.

Limitations

The study's limitations primarily stem from data constraints, including non-overlapping periods for pollution and trade data, which restricted the time-series analysis to a specific 40-year window period. Future studies can focus on other pollutants like methane and nitrous oxide, as well as other mediation factors to pollution other than agriculture which was considered in this study.

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Ethics

The study utilises publicly available secondary data sourced from the World Bank's Development Indicators (WDI). Since this information is freely accessible under the World Bank's Open Data Licence and does not pertain to human subjects, its use in the study raises no ethical concerns.

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