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Research paper

Trade globalization, green taxation and CO2 reduction in sub-Saharan Africa

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Abstract

The target of this investigation is to examine the impact of global commercial activities and green taxation on CO2 emission reduction within sub-Saharan Africa. The fallouts from the VECM suggest that, in the long term, the variables do not have a meaningful bearing on CO2 reduction. However, in the brief period, trade openness, tax revenue, and GDP as moderating factors positively and significantly influence CO2 reduction, whereas foreign direct investment (FDI) is shown to adversely affect the environment. The research advocates for the implementation and integration of green taxes within the tax frameworks of sub-Saharan African nations as a strategy to mitigate environmental pollution. Furthermore, it is recommended that industries and corporations be mandated to adopt renewable energy sources and green technologies for the capture of CO2 emissions, thereby preventing their dispersion into the environment. Governments should explore converting collected CO2 into commercial products.

Keywords: *Environmental Taxes; CO2 Emissions; Pollution Control Costs; Environment and Trade.*

1. Introduction

The connection between trade globalization and its environmental consequences, together with the DATA requirement to secure adequate tax revenue to bolster Sub-Saharan African economies, has become a critical concern. Authorities are focused on boosting revenue through the implementation of green taxation to meet social commitments. Simultaneously, there are efforts to attract foreign investments and engage in international trade. According to Wang et al. (2024), the acceleration of economic growth has been significantly influenced by the industrial revolution and globalization. This upward trajectory has been essential for enhancing social and economic stability; on the other hand, it has also resulted in negative environmental consequences. Yingjun et al. (2024) contend that the consequences of ecological ruin on fiscal health are considerable because it impacts vital sectors, notably agronomy, which is indispensable for food safety and engagement opportunities. Weather variation has led to aquatic shortage and life-threatening meteorological conditions that threaten agronomic output, thus distressing both food safety and fiscal permanency (Yingjun et al., 2024). Trade globalization and industrial revolution dynamics have resulted in a surge of foreign operations that pose environmental risks, leading to the destruction of forests, pollution of waterways, and degradation of farmland in most Sub-Saharan African countries. As Li et al. (2021) pointed out, global warming, air pollution, and other environmental challenges are byproducts of trade globalization, notwithstanding its role in promoting global economic growth.

The increased CO_2 emissions leading to long-term climate change are responsible for raising the typical apparent high temperature of the Globe (Jabeen et al., 2025). Consequently, this increase results in the melting of glaciers, rising sea levels, variations in average rainfall, and the occurrence of droughts in specific regions (Hussain & Dogan, 2021; Su et al., 2023). In accordance with Sustainable Development Goals (SDGs) 13 and 15, the OECD (2012) advocates for intentional measures, such as green taxation, to combat environmental degradation in developing nations. This is particularly pertinent in Sub-Saharan Africa, where the persistent dependence on imported fossil fuels exacerbates environmental harm by elevating CO_2 discharges (Khan et al., 2021; Ibrahim & Ajide, 2022). Thus, to avert the consequences of climate change, it is imperative to cut down on hothouse gas emissions to keep the Earth's temperature from rising. A range of global establishments and initiatives are motivating countries to minimize their ecological secretions to manage this critical challenge (Jabeen et al., 2025). In Nigeria and Ghana, for example, the situation is particularly concerning because most foreign corporations engage in events that are destructive to the atmosphere and pose health risks. In contrast to numerous developed OECD economies shown in Figures 1 and 2 that are currently utilizing carbon taxes to reduce CO_2 emissions, Sub-Saharan Africa continues to face challenges. Although, struggles are underway in various Sub-Saharan African countries to establish environmental tax policies aimed at facilitating the implementation of carbon tax that will boost green technology and environmentally friendly investments by firms and industries in the Sub-Saharan African region. Sabău-Popa et al. (2024) put forward that, the adoption of green taxes can be instrumental in supporting developing countries in their pursuit of a low-carbon conversion, all while advancing a comprehensive and unbiased evolution archetypal. This is exclusively pertinent in less developed countries, where conservative tax restructurings can bolster societal parity.

As outlined by the OECD (2024), green taxation refers to a tax levied on activities that are harmful to the atmosphere, to incentivize environmentally positive behaviors through fiscal benefits. Taxes associated with environmental concerns serve as effective policy tools for influencing the relative pricing of goods and services (OECD, 2024). This mechanism aids in achieving Sustainable Development Goals (SDGs 13 and 15) by alleviating the undesirable conservational impacts connected with industrial practices and bolstering the resilience of biological resources in the face of such challenges. Ediriweera and Wiewiora (2021) opine that green taxation can significantly contribute to the integration of SDGs with their economic feasibility, thus paving the way for the development of green economic systems. From one viewpoint, the successful implementation and promotion of green taxation could enhance environmental sustainability by mitigating scale effects (Shu et al., 2023).

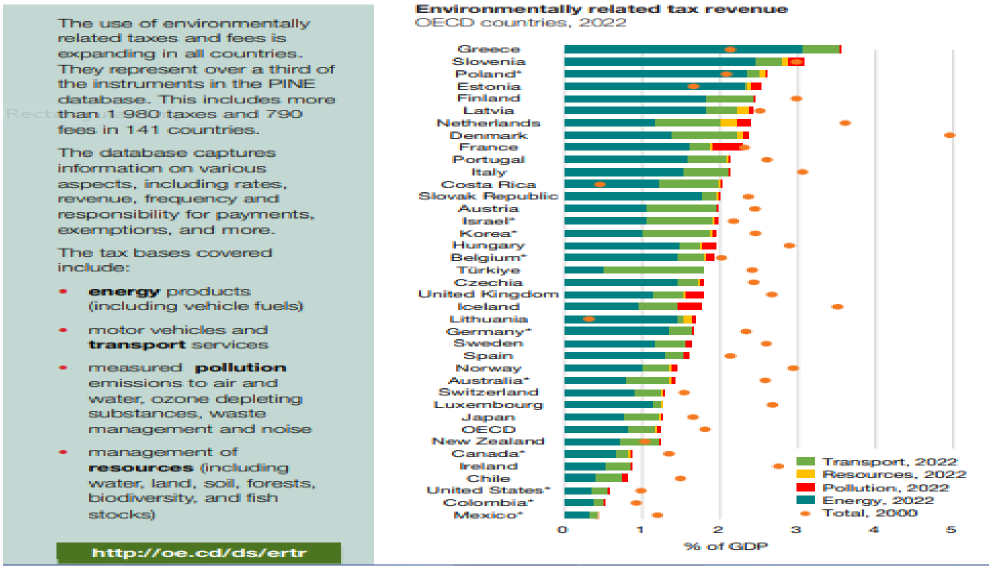

Fig. 1: Tax Revenue from Environmentally Related Sources.

Source: OECD; Link: http://oe.cd/ds/ertr

It has been noted that economic factors play a crucial role in either amplifying or mitigating carbon emissions among the primary drivers of carbon output (Lleshaj & Agaj, 2024). On the other hand, it is also possible that an eco-friendly tax system may foster green surroundings at the cost of unproductivity, which pertains to the lessening of environmental devastation and other resources to maintain economic stability (Khan et al., 2022). This is because green taxes and levies raise the prices of harmful items and operations, thereby discouraging their use and manufacturing, irrespective of their stated aim (OECD, 2024).

There has been debate about the surroundings and the impression of open commercial activities and green taxation on ecological maintenance, and the global reduction of CO_2 emissions remains highly contentious. Numerous researchers have dedicated significant efforts to exploring the association between open trading and ecological excellence. A substantial number of studies (Lleshaj & Agaj, 2024; Mignamissi et al., 2024; Mpuure et al., 2024; Wang et al., 2023) indicate that trade openness significantly contributes to environmental degradation by releasing harmful substances, including CO_2, into the atmosphere, waterways, and the broader environment, thus compromising the health of humans, wildlife, and plant life. Suleman et al. (2024) observed that free trading exerts a substantial and helpful stimulus on economies characterized by high levels of open trading, while it has a detrimental effect on those with little free trading. Conversely, the impression of green taxation on the reduction of CO_2 emissions was deemed both positive and significant by several researchers, including Arcila et al. (2024), Kirikkaleli (2023), Liu (2024), Mehta & Prajapati (2024), Noubissi et al. (2023), and Savranlar et al. (2024). In contrast, Xu et al. (2024) unveiled that corporate statutory taxes have a negative effect on the green environment, as companies often seek to expand their operations to fulfill their tax obligations. Given these conflicting findings and the lack of substantial research from sub-Saharan African economies, the current inquiry purposes to address the breach by assessing the role of free commerce and green taxation in CO_2 reduction within the sub-Saharan African context.

This research enhances social political theory by elucidating the advantages of green taxation in reducing CO_2 emissions. It emphasizes that foreign corporations operating in the region must adhere to tax policies that promote environmental integrity. The current study aims to clarify the benefits associated with the introduction and implementation of a green tax framework in sub-Saharan Africa as a viable approach to managing environmental pollution in the region. Following the introduction, the ensuing segments of this work are arranged in the following order: Unit 2 probes the notional underpinnings and the latest empirical research related to the effects of trade globalization and green taxation on CO_2 emissions. Section 3 outlines the methodological aspects, encompassing data collection and model development, which are essential for achieving the aims of the inquiry. Segment 4 provides a review and argument of the practical outcomes of past studies. In conclusion, Segment 5 completes the findings and their implications for strategic steps relevant for the authorities in the regions under study.

2. Review of related literature

2.1. Conceptual issues in this study

2.1.1. Green taxation and pollution

Green taxes are the primary tools for limiting environmentally harmful activities. These are taxes paid by manufacturers as well as product users for any operation that emits pollutants (Sabău-Popa et al., 2024). Environmental and carbon taxes are included in the broader category of green taxes, which are important eco-friendly pecuniary strategies. They may assume various forms, including power taxes, contamination levies, transportation duties, and reserve dues (Sabău-Popa et al., 2024). A carbon tax is a regulatory tool that elevates the worth of commodities and facilities about the carbon emissions produced through their manufacture and use (Mintz-Woo, 2023). The primary aim of such taxes is to account for the external costs that would typically impact society (Pigou, 1932). Raising taxes on energy sources, such as petroleum and coal, responsible for pollutants and global warming, allows legislators to recognize the social costs associated with their use (Stameski et al., 2024). A well-designed carbon tax ought to align with the societal charge for pollution, denoting the genuine expense to the social order associated with the emission of one more ton of carbon dioxide (CO_2), as measured against a baseline consumption pathway (Mintz-Woo, 2023). The use of this technique can encourage a shift to less harmful and more environmentally friendly energies, such as sunlight and wind energy, eventually benefiting the environment and lessening reliance on petroleum and natural gas. Providing monetary assistance for clean energy sources can increase awareness of eco-friendly technology and infrastructure, leading to a cleaner energy infrastructure (Stameski et al., 2024).

Similarly, Liu (2024) posits that conservational toll guidelines seek to adopt the outward outlays associated with effluence by imposing charges on ecologically detrimental activity. They want to compensate people, entities, and industries for reducing their environmental effects and transitioning to more sustainable practices.

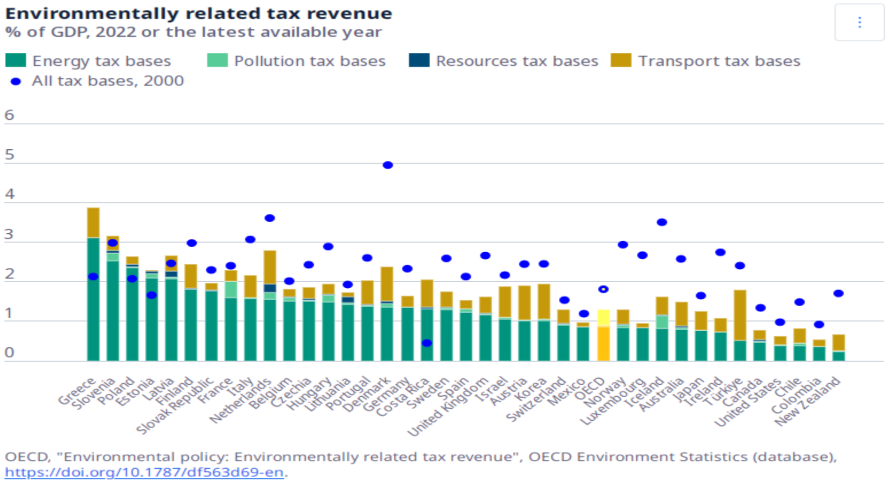

Fig. 2: OECD Environmentally Related Tax Revenue. Link: Https://Doi.Org/10.1787/Df563d69-En.

Wijethunga et al. (2024) assert that the effective expansion of a fiscal system (including a green tax structure) plays a critical part in enabling the move in the direction of a net-zero carbon footprint. Indicating that the fume discharges must be scientifically absorbed to maintain a pollution-free atmosphere. Thus, the efficacy of eco-friendly tax guidelines varies depending on how they are designed, implemented, and what ecological issues are being tackled (Liu, 2024). The OECD Policy Instruments for the Environment (PINE) include a range of tax bases, which are: energy goods, together with automobile energies; cars and conveyance amenities; discharges of pollutants to midair and sea, ozone diminishing elements, specific non-point bases of aquatic contamination, trash organization, and clatter; along with the running of resources such as river, earth, loam, timberlands, surroundings, flora and fauna, and trawl stocks (OECD, 2024). The tax bases associated with ecological concerns, as illustrated in Figures 1 and 2, serve as instances of green taxes that countries are anticipated to implement to regulate CO_2 emissions produced by corporations and private enterprises. As noted by Arcila et al. (2024), tax policy initiatives aimed at controlling pollutants are effective in significantly diminishing the presence of Particulate Matter and Carbon Monoxide. These green taxes not only enhance environmental sustainability but also contribute to the generation of government revenue necessary for meeting social responsibilities. Stameski et al. (2024) equally affirm that green taxes play a noteworthy role in promoting the GDP growth of a region.

2.2. Theoretical reinforcements

2.2.1. The pollution haven hypothesis (PHH)

The prevailing belief is that open trade brings forth new technologies, encourages innovation, and leads to environmental advancements in developing countries. However, the PHH presents a divergent perspective on the implications of international trade for emerging economies. The Pollution Haven Hypothesis (PHH) states that advanced economies have more stringent ecological laws than developing countries. This situation undermines the present advantageous position, causing polluting businesses to shift their operations from industrialized to emerging economies, which are termed as waste safe spaces or "pollution havens". According to the PHH, the reality is that developing countries have become trash havens for more affluent countries because of their participation in trade globalization (Gill et al., 2018). In advanced economies, carbon taxation is too high to bear, and green technology is well emphasized, while in the sub-Saharan African region, green tax is gradually becoming part of the tax system as a means of controlling toxic emissions.

2.2.2. Environmental Kuznets curve (EKC)

The EKC, or Environmental Kuznets Curve, is attributed to Simon Kuznets, who suggested that income inequality initially increases and later decreases as a nation undergoes economic development (Stern, 2018; Wang et al., 2024). The emission of pollutants, including carbon dioxide, sulfur, and nitrogen oxides, is intricately linked to energy consumption. Therefore, the EKC functions as a model (see Figure 3) that examines the relationship between energy use, economic growth, and environmental sustainability.

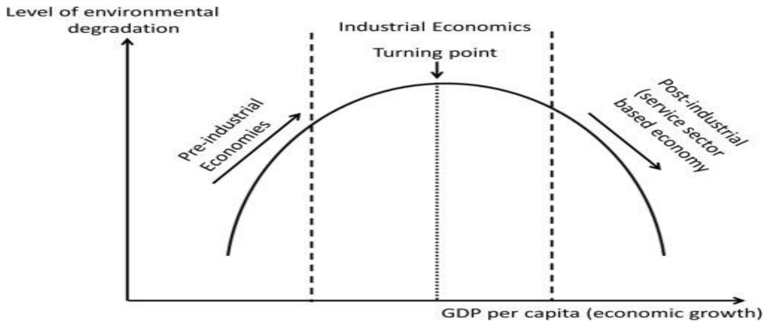

Fig. 3: Environmental Kuuznets Curve. Adapted from: Prasad, (2024)

As shown in Figure 3, EKC suggests that the initial phase of economic development is marked by environmental decline. In contrast, as economic prosperity continues, society tends to foster a more positive relationship with the environment, resulting in diminished degradation (Prasad, 2024). This theory explains the study by illustrating how increased openness to global trade and income enhancement efforts can lead to environmental pollution. This phenomenon arises from a surge in energy consumption, which results in significant carbon dioxide emissions and other chemical components that contribute to carbon footprints. As the environment interacts with the heightened economic activities facilitated by trade liberalization, the necessity for pollution reduction measures, such as carbon taxation, becomes evident. These strategies enable organizations to identify optimal pollution control methods to avoid excessive taxation, promoting the adoption of green technologies as a means of supporting environmental sustainability. Thus, the advancement of any economy will likely require the implementation of green taxation, technological innovations, and other initiatives to mitigate pollution, as shown in Figure 3.

2.3. Evaluation of earlier scholarly works

2.3.1. Empirical evidence on the effect of trade globalization on climate change

Wang et al. (2024) steered an analysis utilizing panel data from 2000 to 2018, collected from 96 developing nations, to investigate the connection between free trading and ecofriendly superiority. The results exposed that trading without international barriers significantly influenced environmental quality in these countries, exhibiting a threshold effect. Additionally, it was found that increased natural resource rents positively contributed to the enhancement of environmental quality, while effective corruption control played a role in mitigating pollution levels. Mignamissi et al. (2024) reported fresh findings on the association between freedom of trade and carbon dioxide outputs in Africa. It verified the contamination-safe concept and demonstrated that openness to trading promotes the release of CO_2 in African territories. But the pliability diverges substantially contingent on which freedom of commerce measurements are utilized. Furthermore, the study observes that commercial liberalization increases the release of carbon dioxide in North Africa, South Africa, and West Africa while decreasing CO_2 outputs in East Africa and Central Africa.

Suleman et al. (2024) piloted a systematic analysis of the influence of macroeconomic factors on CO_2 emissions, concentrating on economies with large and small international trade. Their findings revealed that free global trading positively and meaningfully affected CO_2 releases in economies characterized by extensive global commerce, while exhibiting an undesirable sway in economies with truncated global trading. Mpuure et al. (2024) considered the potential impact of eco-friendly institutions on pollution reduction, differing from previous research by focusing on how policies and establishments for eco-friendly initiatives allay the negative imprint of both amassed and disjointed commercial activities on the atmosphere in Sub-Saharan Africa. The study examined data from 24 sub-Saharan African nations between 2005 and 2020. The fallouts showed that the negative impacts of both inclusive and disconnected trading on ecological degradation were dramatically reduced. Furthermore, the connecting scrutiny found a reciprocal association between overall commerce and environmental deterioration.

The research conducted by Lleshaj and Agaj (2024) focused on the effects of trade development and additional fiscal factors on CO_2 emissions as an environmental indicator in Southeast Europe. The study found that a 1% upsurge in power consumption corresponds to a 1.3% intensification in orangery emanations at the regional level, impacting air quality parameters. Additionally, a 1% escalation in global trading was associated with a 0.13% intensification in CO_2 production. An (2024) explored the dynamics between trade costs and haze production in 12 countries involved in the Regional Comprehensive Economic Partnership (RCEP). The results indicated that a reduction in trade expenses was linked with a decline in environmental pollution. The facilitation of RCEP is likely to lead to lower commerce-connected smog, signifying that minimizing trade outlays can play a role in mitigating ecological effluence.

Wang et al. (2023) examined the influence of free trade and heterogeneity on greenhouse gas emissions in G20 nations from 1997 to 2019. The findings revealed that the influence commerce has on the production of carbon varies; trade liberalization increases the production of carbon dioxide, but trade diversity reduces emission levels. Furthermore, import flexibility has the greatest impact on lowering carbon dioxide emissions.

2.3.2. The role of ecofriendly taxation in CO2 decrease

Noubissi et al. (2023) investigated the effects of environmental guidelines on ecological excellence across 36 OECD nation states from 1994 to 2018. The discoveries indicated that the implementation of environmental taxes plays a momentous part in decreasing CO_2 emissions in both the transport and industrial sectors. In alignment with the SDGs 7 and 13, Kirikkaleli (2023) indicated that taxes related to environmental issues contributed to the reduction of eco-unfriendly dilapidation in the Netherlands, whereas major energy consumption had a detrimental impact on ecological sustainability. According to the findings of Zhong et al. (2024) in 282 cities in China, the application of the Environmental Protection Tax (EPT) is effective in decreasing carbon intensity (CI) through the reduction of pollutant production and the promotion of green innovation. The study revealed significant county dissimilarities in the effectiveness of EPT for carbon reduction, noting that its impact on CI is particularly strong in medium-tax counties, areas with limited conservational worry, typical city centers, and eastern regions.

Stameski et al. (2024) led an enquiry to confirm the significance of carbon income taxes in affecting Nordic financial growth from 2013 to 2022. The statistical results of multiple panel analyses indicated that energy and transport tax collections had a considerable and beneficial influence on financial growth as assessed by GDP per person. Furthermore, pollutant tax revenues had a beneficial, although not substantial, influence on GDP per person in these nations. Liu (2024) looked at the complex relationship between environmental taxes, environmentally friendly technologies, environmentally conscious outlay, actual GDP, and ecological damage in China. The findings demonstrated that green tax policies had a significant impact in both the brief and extended period, with encouraging surprises that led to a reduction in smog levels. Furthermore, swings in green investment, whether good or negative, have been shown to increase pollution levels over time. In addition, real GDP was linked to short-term pollutants abatement. Mehta and Prajapati (2024) observed that environmental taxes have adverse effects on CO_2 emissions, demonstrating that fume discharges decrease once events that produce pollution are subjected to taxation. This fiscal policy tool alters the behavior of the industrial sectors in the EU27 countries by discouraging contaminating practices.

Liu and Zhu (2024) conducted a study on the effects of carbon tax policies on carbon emissions, particularly regarding the spread of eco-friendly technical know-how among producers. Their evenness breakdown demonstrated that implementing the pollution levy rule effectively facilitates carbon drop, and producers are benefiting from eco-friendly technical devices, which are encouraging increased investment in these technologies. According to the conclusions of Soto (2024), China's FDI throughout Europe does not add to the contamination of the air but rather exerts a beneficial influence. The inclusion of environmental taxes screened out non-polluting expenditures, which exhibited an irregular correlation with pollutant levels. The research also determined that pollution in the atmosphere is inextricably related to the broader ecological situation, accentuating the beneficial consequences of worldwide climate change accords.

The research conducted by Arcila et al. (2024) focused on how changes in the taxation of commodities and services obtained affected automobile emissions, utilizing autonomous disparity from a normal test in China. The outcomes indicated that the taxing approach, which increased the tax rate for automobiles with larger engines, successfully reduced emissions of all toxins analyzed, with the maximum noteworthy decline of 11% observed in pollutant substance. The inquiry of Savranlar et al. (2024) concentrated on the effects of eco-friendly levies on pollution in the EU-27-member states. The findings showed that increasing these taxes led to a 0.14% reduction in CO_2 production. Moreover, the fallouts of the interconnection assessment indicated a mutual association between CO_2 emissions and environmental taxes. Bretschger and Grieg (2024) used the synthetic control approach to analyze the efficiency of carbon taxes after the fact. The analysis concluded that the tax had substantial effects on CO_2 emissions from transportation, but no obvious influence on productivity.

The findings of Xu et al. (2024) illustrated that the corporate statutory tax rate positively correlated with CO_2 emissions, resulting in a worsening of environmental quality, while also negatively influencing environmental innovation and limiting the progress of green innovation. Xu and Lin (2024) presented empirical findings that demonstrated a reversed U-shaped upshot of green finance on municipal toxin concentration. This suggests that the carbon reduction impact of green investment evolves from being relatively minor in the initial stages to becoming more substantial in later stages. Additionally, the analysis from the perspectives of region, city size, and carbon strength showed that the influence of green investment on numerous carbon forces exhibited clear nonlinear traits. The enquiry directed by Sabău-Popa et al. (2024) focused on the interplay between GDP per capita fluctuations, key and replaceable power usage, greenhouse gas emissions, and green taxes. The study's results highlighted a weighty constructive connection between main energy usage and both overall ecological duties and levies from power sources. Additionally, it was found that changes in GDP per capita had a significant and positive influence on transport and pollution taxes. In contrast, the study concluded that net hothouse smoke production, as well as the stream, conversion, and usage of replaceable energy resources and waste, did not have a significant impact on the overall green taxes and their various components.

Jabeen et al. (2025) discovered that reducing CO_2 intensity and greenhouse gas releases led to an improvement in ecological conditions through increased environmental tax revenues. The overall impact of tax revenues associated with environmental initiatives surpassed that of revenues from the energy sector. Additionally, both factors related to environmental tax revenues had a significantly greater influence on greenhouse gas emissions than CO_2 intensity alone. Moreover, the transition to sustainable energy played a critical part in decreasing both greenhouse gas emissions and CO_2 intensity.

3. Methodology

The typical Vector Error Correction Model (VECM) that captures both long-run and short-run dynamics is outlined as follows:

$$\Delta Yt = \sigma + \sum_{i=1}^{k-1} \gamma i \Delta Yt - i + \sum_{j=1}^{k-1} \eta j \Delta Xt - j + \sum_{m=1}^{k-1} \xi m \Delta Rt - m + \lambda ECTt - 1 + \mu t \ldots \quad (1)$$

Where:

$ECTt - 1$ = signifies the lagged residual produced by the ordinary least squares approach, which is derived from the long-run co-integrating equation:

$$Yt = \sigma + \eta j Xt + \xi \mu t$$

The co-integrating equation can be articulated as: $ECTt - 1 = [Yt - 1 - \eta^1 Xt - 1 - \xi^1 Rt - 1]$. This formulation of the Error Correction Term (ECT) signifies that the prior period's deviation from long-run equilibrium, identified as the error, plays a role in shaping the short-run fluctuations of the dependent variable.

In this context, λ denotes the coefficient associated with the Error Correction Term (ECT) and reflects the speed of adjustment. It assesses the rate at which the dependent variable, y, returns to its equilibrium position after experiencing changes in X and R.

This study employs the following Vector Error Correction Model (VECM) for its analysis:

$$\Delta LnCO2t = \propto + \sum_{i=1}^{k-1} = \beta i \Delta LnCO2t - i + \sum_{j=1}^{k-1} = \emptyset j \Delta LnTOPt - j + \sum_{l=1}^{k-1} = \emptyset j \Delta LnTRVt - l + \sum_{l=1}^{k-1} = \emptyset j \Delta LnFDIt - l + \sum_{m=1}^{k-1} = \varphi m \Delta LnGDPt - m + \lambda_1 ECTt - 1 + \mu_1 t \quad (2)$$

$$\Delta LnTOPt = \propto + \sum_{i=1}^{k-1} = \beta i \Delta LnTOPt - i + \sum_{j=1}^{k-1} = \emptyset j \Delta LnCO2t - j + \sum_{l=1}^{k-1} = \emptyset j \Delta LnTRVt - l + \sum_{l=1}^{k-1} = \emptyset j \Delta LnFDIt - l + \sum_{m=1}^{k-1} = \varphi m \Delta LnGDPt - m + \lambda_1 ECTt - 1 + \mu_1 t \quad (3)$$

$$\Delta LnTRVt = \propto + \sum_{i=1}^{k-1} = \beta i \Delta LnTRVt - i + \sum_{j=1}^{k-1} = \emptyset j \Delta LnTOPt - j + \sum_{l=1}^{k-1} = \emptyset j \Delta LnCO2t - l + \sum_{l=1}^{k-1} = \emptyset j \Delta LnFDIt - l + \sum_{m=1}^{k-1} = \varphi m \Delta LnGDPt - m + \lambda_1 ECTt - 1 + \mu_1 t \quad (4)$$

$$\Delta LnFDIt = \propto + \sum_{i=1}^{k-1} = \beta i \Delta LnFDIt - i + \sum_{j=1}^{k-1} = \emptyset j \Delta LnTOPt - j + \sum_{l=1}^{k-1} = \emptyset j \Delta LnTRVt - l + \sum_{l=1}^{k-1} = \emptyset j \Delta LnCO2t - l + \sum_{m=1}^{k-1} = \varphi m \Delta LnGDPt - m + \lambda_1 ECTt - 1 + \mu_1 t \quad (5)$$

$$\varDelta \mathrm{LnGDPt} = \propto + \sum_{i=1}^{k-1} = \beta i \varDelta \mathrm{LnGDPt} - i + \sum_{j=1}^{k-1} = \emptyset j \varDelta \mathrm{LnTOPt} - j + \sum_{l=1}^{k-1} = \emptyset j \varDelta \mathrm{LnTRVt} - l + \sum_{l=1}^{k-1} = \emptyset j \varDelta \mathrm{LnFDIt} - l + \sum_{m=1}^{k-1} = \varphi m \varDelta \mathrm{LnCO2t} - m + \lambda_1 \mathrm{ECTt} - 1 + \mu_1 t \quad (6)$$

Where:
The notation Ln refers to the natural logarithm, t is used for time, k signifies the maximum lag, and β represents the coefficients. Ø indicates the difference in parameters, while $\varDelta$ denotes the difference operators. The expression K – 1 shows that the lag length is reduced by one, and λ is the speed of adjustment parameter, which is indicated with a negative sign.
$\beta i, \emptyset j, \varphi m$ = represents the short-term kinetic coefficients associated with the modification of the model for long-term stabilization. The term $\mathrm{ECTt} - 1$ denotes the error correction term, which reflects the lagged value of the residuals derived from the co-integrating regression of the dependent variable with the explanatory variables. Information regarding the long-term dynamics is obtained from the long-run co-integrating relationship. The variable $\mu_1 t$ signifies the residuals, often referred to as stochastic error terms, impulses, innovations, or shocks.

Table 1: Study Materials and Dimensions

Applied cryptographs	Meaning	Amount and period	Sources
Dependent			
$LNCO_2$	The gaseous leaks are produced by the burning of petroleum and coal and the manufacturing of clinker. The pollutants include greenhouse gases produced from the combustion of fluid, solid, and gaseous petroleum products, as well as gas burning operations.	Kilotons of CO_2. Data collected cover a period from 1990-2023.	World Bank Development Indicators (WDI)
Independents			
LNTOP	Trade expressed as a proportion of GDP	The fraction of the entire of exports and imports to GDP. Data span 1990 – 2023.	WDI
LNTRV	Overall tax proceeds as % of GDP	The ratio of total tax revenue to GDP. Data range from 1990-2023.	WDI
LNFDI	Foreign Direct Investments	Billion USD. Data span 1990 – 2023.	WDI
Moderating			
LNGDP	Gross Domestic product	Billion USD. Data duration is from 1990-2023.	WDI

Source: Author's information on data collection, 2024

In Table 1, the variables relevant to this study are detailed. The dependent variable is fundamentally the CO_2 emissions in sub-Saharan Africa, as reported by the World Bank Development Indicators. The independent variables include trade openness, tax revenue, and foreign direct investment, while GDP serves as the moderating variable, with the data collected in billions of USD. Due to varying measures, all data are used in their natural log transformation.

4. Results

In this section, the results and interpretation of the data analysis for this study are provided. The results feature the trend analysis represented in Figure 4, descriptive statistics summarized in Table 2, unit root analysis found in Table 3, VAR lag order selection criteria presented in Table 4, Johansen co-integration findings in Table 5, Vector Error Correction Estimation results in Table 6, and the diagnostic tests results as shown in Table 7.

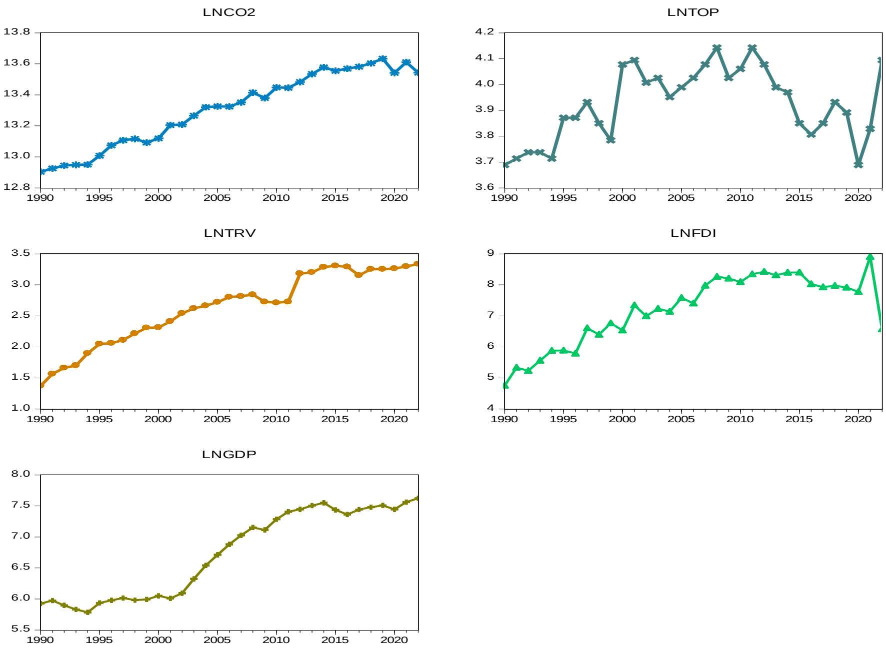

Fig. 4: Trend of Data from 1990-2023.

The trend analysis presented in Figure 4 indicates that CO_2 emissions reached their highest level in 2019. In contrast, during the early 1990s, emissions were relatively insignificant. However, the increase in multinational corporations, driven by trade liberalization and the desire to facilitate the transfer of technology and ideas, has led to a significant rise in CO_2 emissions across sub-Saharan African countries.

The period from 2008 and 2010 marked an increase in openness to trade, which subsequently faced a minor decline in the following years, only to rise again in 2023. Foreign investment has been on an upward trajectory, although a significant drop was observed in 2023. In contrast, tax revenue and GDP have maintained a steady growth throughout the years.

Table 2: Descriptive Statistics

	CO_2	TOP	TRV	FDI	GDP
Mean	13.31	3.924	2.626	7.211	6.736
Median	13.32	3.932	2.721	7.405	6.881
Maximum	13.63	4.143	3.336	8.908	7.624
Minimum	12.90	3.689	1.374	4.753	5.784
Std. Dev.	0.239	0.139	0.584	1.115	0.698
Skewness	-0.269	-0.185	-0.486	-0.562	-0.089
Kurtosis	1.690	1.844	2.152	2.188	1.242
Jarque-Bera	2.758	2.027	2.291	2.646	4.295
Probability	0.252	0.363	0.318	0.266	0.116
Sum	439.1	129.4	86.67	237.9	222.3
Sum Sq. Dev.	1.836	0.626	10.92	39.78	15.59
Observations	33	33	33	33	33

Author's calculation, 2024

The central aim of descriptive statistics is to establish that the datasets are normally distributed and entirely suitable for the study. The results shown in Table 2 demonstrate that the mean values of all variables surpass the standard deviation values, indicating a narrower spread of the datasets. This finding is not alarming, as the Kurtosis falls within the acceptable range and the Jarque-Bera p-values are above 0.05. Thus, the data distribution for this study is confirmed to be normal.

Table 3: Unit Root Result

Variable	ADF-Statistics	Critical value @ 5%	P-value	Order of Integration
lnCO2	-7.082	-2.960	0.000	I(1)
lnTOP	-5.511	-2.964	0.000	I(1)
lnTRV	-5.372	-2.960	0.000	I(1)
lnFDI	-9.168	-2.960	0.000	I(1)
lnGDP	-3.444	2.960	0.017	I(1)

Author's calculation, 2024

The unit root analysis results displayed in Table 3 reveal that all variables are stationary at their first difference, indicating the possibility of both long-run and short-run relationships among them. To further validate this assumption and ascertain the existence of co-integration—either long-term or short-term—among the variables under investigation, a Johansen and Max-eigenvalue Co-integration Rank Test has been conducted, as detailed in Table 5. The unit root examination is crucial for establishing the stationarity of the datasets, which helps to avoid incorrect analyses and interpretations.

Table 4: VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	40.62	NA	6.918	-2.298	-2.067	-2.223
1	162.4	196.4	1.380	-8.540	-7.153	-8.088
2	206.2	56.55*	4.691*	-9.755*	-7.211*	-8.926*

* Indicates Lag Order Selected by the Criterion Author's Calculation, 2024

The results of the VAR lag order selection criteria, as shown in Table 4, are required to ascertain the lag order selected by all criteria used in the evaluation. In Table 4, it is evident that the lag order preferred by all criteria is 2, which is then utilized in the Johansen co-integration test found in Table 5. Table 5 indicates the presence of long-run co-integration, as shown by the Johansen co-integration rank test p-values, which fall below 0.05 in almost all scenarios. The Mas-eigenvalue co-integration rank test supports this conclusion, although its significance levels range from 5% to 10%. Both tests suggest a long-term relationship among the factors analyzed. As a result, it is necessary to conduct a Vector Error Correction Model (VECM) to identify how deviations from earlier periods can be corrected in the current period and vice versa. The results of the VECM are detailed in Table 6.

Table 5: Johansen Co-Integration Rank Test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	P-value
None *	0.867	122.0	69.82	0.000***
At most 1 *	0.525	61.49	47.86	0.001***
At most 2 *	0.468	39.12	29.79	0.003***
At most 3 *	0.339	20.18	15.49	0.009***
At most 4 *	0.227	7.747	3.841	0.005***
Max-eigenvalue Co-integration Rank Test				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	P-value
None *	0.867	60.52	33.87	0.000***
At most 1	0.525	22.37	27.58	0.202
At most 2	0.468	18.94	21.13	0.098*
At most 3	0.339	12.43	14.26	0.095*
At most 4 *	0.227	7.747	3.841	0.005***

*** Significant Level At 1%; ** Significant Level at 5%; * Significant Level at 10%. Author's Calculation, 2024.

Table 6: Vector Error Correction Estimates Long Run Estimation Result

Cointegrating Eq:	CointEq1
$LNCO_2$(-1)	1.000
LNTOP(-1)	3.922(0.4)
LNTRV(-1)	0.543(0.2)
LNFDI(-1)	-1.039(0.1)
LNGDP(-1)	0.391(0.1)
C	-25.18

Short Run VECM Estimation Result

Error Correction:	D($LNCO_2$)	D(LNTOP)	D(LNTRV)	D(LNFDI)	D(LNGDP)
CointEq1	-0.033(0.03)**	-0.244(0.06)*	0.117(0.07)*	1.248(0.23)	-0.030(0.06)*
D($LNCO_2$(-1))	-0.632(0.22)	-0.662(0.54)	-1.135(0.65)	-6.701(2.05)	-0.496(0.52)
D(LNTOP(-1))	0.062(0.09)*	0.434(0.22)	0.062(0.26)	-1.517(0.81)	-0.347(0.21)
D(LNTRV(-1))	0.078(0.07)*	0.054(0.16)	-0.023(0.19)	-0.481(0.59)	0.031(0.15)
D(LNFDI(-1))	-0.009(0.03)**	-0.076(0.06)*	0.140(0.07)*	-0.188(0.22)	-0.017(0.06)*
D(LNGDP(-1))	0.044(0.09)*	0.411(0.19)	-0.026(0.24)	-0.574(0.75)	0.717(0.19)
C	0.028(0.01)	0.011(0.02)	0.067(0.02)	0.285(0.08)	0.028(0.02)
R-squared	0.313	0.506	0.212	0.753	0.408
Adj. R-squared	0.142	0.383	0.014	0.692	0.261
S.E. equation	0.037	0.083	0.099	0.313	0.080
F-statistic	1.826	4.109	1.075	12.23	2.767

Author's Calculation, 2024. *** Significant Level at 1%; ** Significant Level at 5%; * Significant Level at 10%.

Table 7: Vec Residual Heteroskedasticity Tests

Chi-sq	Prob.
162.8	0.816

VECM Residual Serial Correlation LM Tests

LM-Stat	Prob
16.01	0.914
33.16	0.127

Author's calculation, 2024.

4.1. Discussion on results

In Table 6, the results from the long and short run estimations of the VECM are summarized. The long run results indicate that trade openness, tax revenue, and GDP have a practically insignificant encouraging outcome on the reduction of CO_2 emissions, while foreign direct investment (FDI) has a minor negative effect over the long period. This depicts the relevance of enhancing tax revenue mobilization in sub-Saharan Africa to effectively manage environmental challenges. Considering this, the governments in sub-Saharan Africa need to incorporate a green tax framework into their tax policies to address environmental pollution. This is consistent with social political theory, which maintains that individuals and corporations are required to pay taxes that enable the government to fulfill its social responsibilities, including tackling environmental issues. Additionally, monitoring and regulating foreign direct investment in these regions is crucial to mitigate health risks and prevent environmentally damaging practices.

The term for error correction, referred to as CointEq1 in Table 6, is considerably relevant at the 0.05 level. Thus, the result implies that the departure from the long-term equipoise observed in prior years are adjusted at a rate of 3.3% in the current year. However, in the short run, trade openness positively impacts CO_2 emissions, with a significance level of 10%. This finding is in toeing line of the inferences of Suleman et al. (2024), who found that economies with a high degree of trade openness experience advantages. Conversely, this research contradicts a substantial number of studies that argue trade openness is detrimental to environmental health (Ibrahim & Ajide, 2022; Lleshaj & Agaj, 2024; Mignamissi et al., 2024; Mpuure et al., 2024; Wang et al., 2023). Similarly, tax revenue demonstrates a positive impact on CO_2 emissions at a significance level of 10%. This finding aligns with the research conducted by Arcila et al. (2024), Kirikkaleli (2023), Liu (2024), Mehta & Prajapati (2024), Noubissi et al. (2023), and Savranlar et al. (2024), which indicates that the implementation of a carbon tax can mitigate the environmental harm associated with CO_2 emissions. Conversely, Xu et al. (2024) reported that corporate statutory taxes negatively affect the green environment, as businesses often strive to expand their operations to meet tax requirements.

Additionally, GDP positively influences CO_2 emissions at a 10% significance level in the short term. In contrast, foreign direct investment (FDI) exhibits a significant negative effect on CO_2 emissions at a 5% significance level. This result reinforces the argument that Multinational Corporations should be obligated to pay additional taxes, particularly green taxes, aimed at alleviating the pollution resulting from their business activities. This notion is in accordance with the social political theory discussed in section 2.2, which emphasizes the importance of tax contributions from both individuals and corporations to enable the government to perform essential social functions, ultimately fostering a sustainable, healthy, and accommodating environment for everyone. To confirm the findings of this study, a post-estimation analysis was conducted, with the results presented in Table 7. Both tests indicate that there is no serial correlation present in the series under examination, and there is a lack of heteroskedasticity. Therefore, the model utilized in this study is deemed to be a suitable fit.

5. Summary

This research focuses on assessing the effects of trade openness and green taxation on the reduction of CO_2 emissions in sub-Saharan Africa. The analysis is based on annual data collected from 1990 to 2023 and employs the Vector Error Correction Model (VECM), prompted by unit root results indicating that all series are stationary at their first difference. The Johansen and Max-eigenvalue Co-integration Rank Tests further support the presence of a long-term relationship among the variables. The VECM analysis reveals that, over the long term, none of the variables significantly contributes to CO_2 reduction. In contrast, in the short term, trade openness, tax revenue, and GDP as moderating factors have positive and significant effects on CO_2 reduction, while foreign direct investment (FDI) is found to negatively impact the environment more severely. Therefore, the governments in the sub-Saharan African region should intensify efforts to the introduction of green taxes to combat the environmentally harmful activities of foreign corporations. These activities lead to high emissions of

CO_2 into the environment, and if the pollution levels are subjected to high taxes, the foreign corporations will resort to environmentally friendly energies and technologies to reduce their tax liabilities, and this will, in turn, gradually restore the green environment we all desire to have.

Despite the presence of various environmental taxes in the Sub-Saharan African region, including hydrocarbon and oil, and gas flaring taxes, it is vital to align with the global movement aimed at preventing global warming through the implementation of green taxation. Therefore, this study recommends a green tax structure that will support environmental sustainability across the sub-Saharan African regions. The study emphatically recommends the adoption and integration of green taxes into the tax systems of sub-Saharan African countries as a strategy to alleviate pollution in their environments. It is recommended that industries and corporations be required to utilize renewable energy sources and implement green technologies to effectively capture CO_2 emissions, thus preventing their release into the atmosphere. Environmental Agencies should mandate companies with high polluting activities to employ carbon capture technologies such as Direct Air Capture, which uses filtering methods to absorb CO_2 straight from the air around us, and subsequently condenses it for storing or transformation into valuable goods. The policy implication is that the governments of Sub-Saharan African countries should explore innovative methods of absorbing carbon and transform it into commercially viable products.

This study aligns with Sustainable Development Goal (SDG) 13, which calls for immediate steps to tackle global warming and associated consequences, as well as SDG 15, which seeks to maintain, rebuild, and foster healthy usage of ecological systems to preserve vegetation, prevent aridity, and correct land damage and biodiversity extinction. Additionally, further research should focus on evaluating the introduction, implementation, and effectiveness of these green taxes in mitigating environmental pollution. The study advocates for the adoption of green technologies that facilitate CO_2 collection, recycling, and commercialization for the benefit of both humanity and economic growth. However, this study is constrained by a lack of data, as the author was unable to access specific green taxes currently in effect in the sub-Saharan African regions. The data utilized pertains to total tax revenue as a percentage of GDP. Consequently, the study urges sub-Saharan African governments to enhance the availability of data to support research aimed at improving the environmental integrity of the region.

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