UNIVERSITY OF CAPE COAST

PUBLIC DEBT, GREEN COMMITMENT AND ENVIRONMENTAL QUALITY IN SUB-SAHARAN AFRICA

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BY

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FEBRUARY 2025

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been published or presented for another degree in this University or elsewhere.

Candidate's Signature…………………………… Date …..……………

Name: Samuel Obeng

Supervisor's Declaration

I hereby declare that the preparation and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Supervisor's signature………………………...... Date …..……………

Name: Prof. Francis Kwaw Andoh

ABSTRACT

Knowing the extent to which the fiscal state of a nation exerts pressure on the environment has become crucial in Sub-Saharan Africa. This study examines the effect of public debt on environmental quality, paying particular attention to the threshold at which the effect becomes nonlinear and the mediating role of natural resource extraction. It also examines how the effect of public debt is diluted when nations commit to regional green agreements. Employing panel data from 2007 to 2020 in 37 Sub-Saharan African countries, the system generalised method of moments (GMM) and dynamic panel threshold estimation techniques are utilised to achieve the study's objectives. The results reveal that public debt degrades environmental quality and that resource extraction mediates this relationship in the sub-region. However, public debt exhibits a non-linear relationship with a threshold value of 51.5%, below which is not harmful to the environment. Additionally, this study demonstrates that green commitment reduces the negative effects of debt on the environment. The study recommends that sub-Saharan African countries should manage public debt carefully to avoid exceeding the threshold value of 51.5 (% of GDP), where debt begins to be detrimental to the environment. Moreover, countries are encouraged to ratify regional environmental agreements such as the Africa Convention on the Conservation of Nature and Natural Resources.

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DEDICATION

To my family

KEYWORDS

Environmental Quality

Green Commitment

Natural Resource Extraction

Public Debt

Sub-Saharan Africa

LIST OF ABBREVIATION

ADB	Africa Development Bank
AR	Arellano-Bond Test for Serial Correlation
CH_4	Methane
CO_2	Carbon Dioxide Emission
COP	Conference of Parties
DSA	Debt Sustainability Analysis
EITI	Extractive Industry Transparency Initiative
EKC	Environmental Kuznets Curve
EPI	Environmental Performance Index
EU	European Union
EXD	External Debt
FDI	Foreign Direct Investment
GDPG	Growth in Gross Domestic Product
GMM	Generalized Method of Moments
IMF	International Monetary Fund
MDRI	Multilateral Debt Relief Initiative
MF	Material Footprint
N_2O	Nitrous Oxide
PD	Public Debt
REC	Renewable Energy Consumption
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
URBG	Urban Population Growth
WDI	World Development Indicators
YCELP	Yale Centre for Environmental Law and Policy

TABLE OF CONTENTS

Contents **Page**

DECLARATION ii

ABSTRACT iii

ACKNOWLEDGEMENTS iv

DEDICATION v

KEYWORDS vi

LIST OF ABBREVIATION vii

TABLE OF CONTENTS viii

LIST OF TABLES xiii

LIST OF FIGURES xiv

CHAPTER ONE: INTRODUCTION

Background to the Study 1

Statement of the Problem 8

Purpose of the Study 10

Research Hypothesis 11

Definition of Environmental Quality 12

Significance of the Study 12

Delimitations of the Study 12

Limitations of the Study 13

Organisation of the Study 13

CHAPTER TWO: LITERATURE REVIEW

Introduction 14

Theoretical Review 14

Debt Overhang Theory 14

The Environmental Kuznets Curve (EKC) 16

Porter Hypothesis 17

Debt Resource Hypothesis 19

Empirical Review 20

Other Determinants of Environmental Quality 26

Foreign Direct Investment (FDI) and Environmental Quality 26

Economic Growth, Renewable Energy Consumption and Environmental 27

Agriculture Value-added and Environmental Quality 28

Urbanisation, Forest Area and Environmental Quality 29

Industrial Value Added and Environmental Quality 30

Conceptual Framework 31

Chapter Summary 32

CHAPTER THREE: RESEARCH METHODS

Introduction 33

Research Approach and Design 33

Model Specification	34
Data Type and Source	36
Variable Description, Justification and Expected Sign	37
Dependent Variable	38
Environmental Quality	38
Main Independent Variables	40
Moderating and Mediating Variable	41
Control Variables	42
Foreign Direct Investment (FDI)	42
Renewable Energy Consumption	43
Urbanisation	43
Gross Domestic Product (GDP)	43
Productive Structure	44
Forest Area	45
Estimation Procedure	45
Post Estimation Diagnostic Tests	49
Chapter Summary	50
CHAPTER FOUR: RESULTS AND DISCUSSIONS	
Introduction	51
Descriptive Statistics	51

Environmental Performance Index (EPI) for Countries 53

Environmental Performance Index in Terms of Income Groupings 54

Environmental Performance Index in Terms of Regional Groupings 55

Correlation Analysis 56

Linear Effect of Public Debt on Environmental Quality in SSA. 59

Public Debt Threshold for Environmental Quality in SSA 61

Natural Resource Extraction as a Mediator between Debt and Environmental 64

The Relationship between Public Debt and Environmental Quality 66

Effects of Other Variables on Environmental Quality in Sub-Saharan Africa. 70

Post Estimation Results 72

Chapter Summary 72

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction 74

Summary 74

Conclusions 75

Recommendations 76

Areas for Further Studies 77

REFERENCES 78

APPENDICES 79

LIST OF TABLES

Table 1: Measurement of Data and Sources 37

Table 2: Descriptive Statistics 51

Table 3: Pairwise Correlations 58

Table 4: Linear effect of public debt on environmental quality in SSA 59

Table 5: Non-linear relationship between public debt and environmental 62

Table 6: The role of natural resource extraction as a mediator in the debt-environment relationship. 64

Table 7: The Moderating Role of Green Commitment in the Public Debt-environment Relationship. 67

LIST OF FIGURES

Figure 1: Trend of Fossil Fuel Emissions in Africa 1850-2022 2

Figure 2: Trend of general government debt (% of GDP) in the Sub-Region 5

Figure 3: Schematic Representation of the Porters Hypothesis 19

Figure 4: Relationship between Public Debt, Natural Resource Extraction, Green Commitment and Environment Quality 31

Figure 5: Environmental Performance Index by Countries 54

Figure 6: Environmental Performance Index in terms of Income Level 55

Figure 7: Environmental Performance Index in terms of Regional Groupings 56

CHAPTER ONE

INTRODUCTION

This chapter outlines the study's background, statement of the problem, purpose, specific objectives, hypotheses, and significance. It also includes a section defining environmental quality, the study's delimitations, and its limitations, and it concludes with the organisation of the study.

Background to the Study

The environment is an integral part of human life on Earth, and human survival depends on it. The environment directly provides raw materials (timber, minerals and water) needed as essential resources in the process of production. Additionally, the environment indirectly enhances economic activities through ecosystem services, including flood risk management, nutrient cycling, and water purification (Akam, Owolabi & Nathaniel, 2021). In recent times, as a result of anthropogenic actions such as fossil fuel combustion, agricultural practices, and industrialisation, the environment (land, air and water) continues to be polluted, affecting general environmental quality (Singh & Singh, 2017).

The International Energy Agency Report (2022) claimed that global energy-related carbon dioxide emissions ($C0_2$) grew by 0.9 per cent, that is, 321 megatonnes(Mt) in 2022, reaching a new high of over 36.8 gigatonnes(Gt). The Global Set of Climate Rate Statistics and Indicators (2024), asserted that human activities have induced warming to reach 1.14 [0.9 to 1.4] ◦C averaged over the 2013–2022 decade and 1.26 [1.0 to 1.6] ◦C in 2022. While global society struggles with these problems, Africa and its sub-regions face unique environmental challenges.

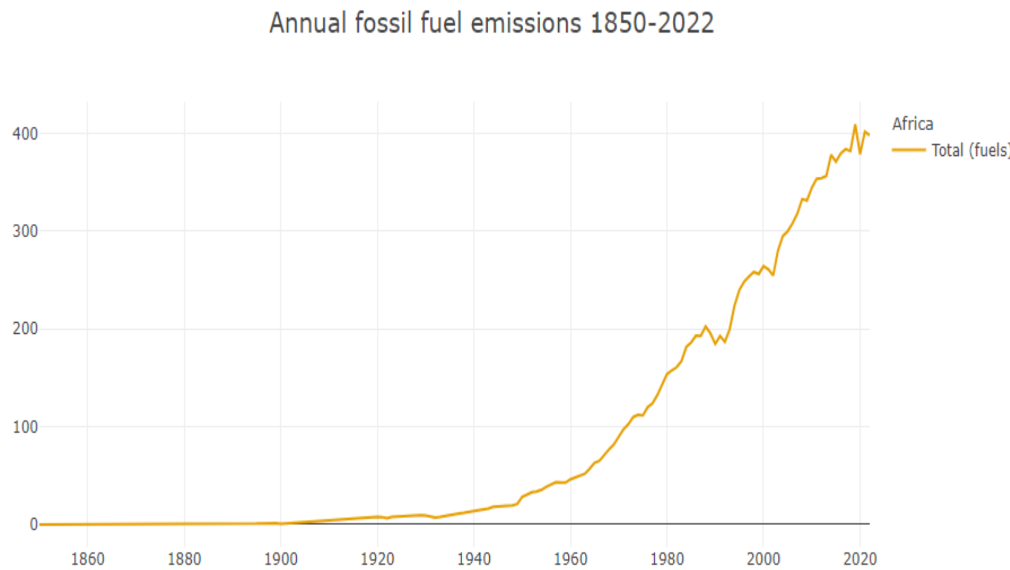

Figure 1: Trend of Fossil Fuel Emissions in Africa 1850-2022

Source: Global Carbon Budget (2023)

Figure 1 shows an upward trend of annual fossil fuel emissions in Africa.

Africa contributes about 4 per cent of the global $C0_2$ emissions, and fossil fuel (coal and oil) and land use account for over 50% of Africa's greenhouse gases (Minx, Lamb, Andrew, Canadell, Crippa, Döbbeling & Tian 2021). According to the World Bank (2020), $C0_2$ emissions (measured in kilotons) in Sub-Saharan Africa (SSA) rose from 806,537.52 in 2013 to 853,107.13 in 2016. Data from Statista (2024) reveals that in sub-Saharan Africa, between 2015 and 2019, land degradation rose from 6.7% to 14.63%. Poor environmental conditions harm economic activities, especially in vulnerable societies like sub-Saharan Africa, where widespread poverty increases reliance on agriculture (Oteng-Abayie, 2022).

National commitment to green agreements, which reflect the extent to which governments are dedicated to supporting sustainable ecological standards (Haldorai, Kim and Gracia, 2022), has been considered an important step in addressing environmental problems. Governments that show strong green commitment often enact stricter environmental policies and regulations, such as emission limits, pollution control and energy efficiency standards. Faezah *et al.* (2024) asserted that the link between an agency's green commitment and environmental improvement is direct because green commitment portrays a sense of obligation toward achieving a targeted ecological goal. Green commitment represents a formal obligation by countries to ensure ecosystem preservation and promote the conservation and responsible usage of natural resources (Ansari *et al*., 2021). This is consistent with the Sustainable Development Goals (SDGs) 13 and 15, which intend to prioritise “climate actions “and ensure the quality of “Life on Land”, respectively (United Nations, 2015).

In this respect, several global initiatives and protocols have been initiated to discuss issues of ecological destruction. Notable examples are the Rio Convention of 1992, the Kyoto Protocol in 1997, the Paris Agreement in 2015 and the latest Conference of Parties COP28 in 2023. These protocols shape global environmental governance and influence policies worldwide. For example, the Paris Agreement hinted the need to limit global warming to below 2°C above pre-industrial levels, with efforts to limit the temperature increase to 1.5°C. The Conference of Parties (COP) focuses on climate change mitigation, climate change adaptability, and climate financing. The Africa Convention on the Conservation of Nature and

Natural Resources has been developed at the regional level to augment these global initiatives by promoting sustainable development by efficiently using Africa's rich natural resources (Unity, 2003). The treaty calls for the conservation of essential habitats, wildlife protection, and sustainable land, water, and forest resource practices (Unity, 2003). To tackle the current evolving environmental issues, the treaty was amended in 2003 to prioritise strengthening modern environmental rules (African Union, 2003). Ecosystem challenges have become the convention's focus, including climate change, air and water pollution, and the responsible usage of natural resources (African Union, 2003). The treaty helps enhance environmental protection, foster the conservation and efficient usage of natural resources, and promote cooperation in research programmes related to environmental conservation, as stated in the convention's objectives (African Union, 2003). So far, 44 countries have signed the convention, but 17 countries have ratified it. By integrating these recent global concerns, the treaty remains relevant as a legal framework for guiding African countries in achieving sustainable development goals.

As these ecological problems heighten, researchers have increasingly concentrated on finding the key factors that influence the environment (Nkemgha, Engone, Honoré, & Belek, 2024). Government debt has emerged as a potential factor that influences the environment. The debt situation in SSA has undergone substantial changes in the last few decades. The 1980s marked a period of increasing debt owing to domestic factors such as poor fiscal discipline, inefficient resource allocation, and exogenous factors, including rising interest rates in developed economies and global economic downtowns (Ndoricimpa, 2020). The global financial crises in 2008 and other factors, such as increasing demand for investment in infrastructure development, export price volatility, weak fiscal management, political instability, exchange rate volatility, and expensive financial sources, the mean total government borrowing (% of GDP) doubled from 27% in 2010 to 52% in 2018 (IMF, 2023a). Furthermore, the COVID-19 pandemic disrupted international and domestic economic transmission channels, and the Russian-Ukraine War increased global oil and food prices, which further exacerbated the growing debt in the sub-region (Heitzigm, Ordu, & Senbet, 2021; Ekeruche, 2022; Were, 2024).

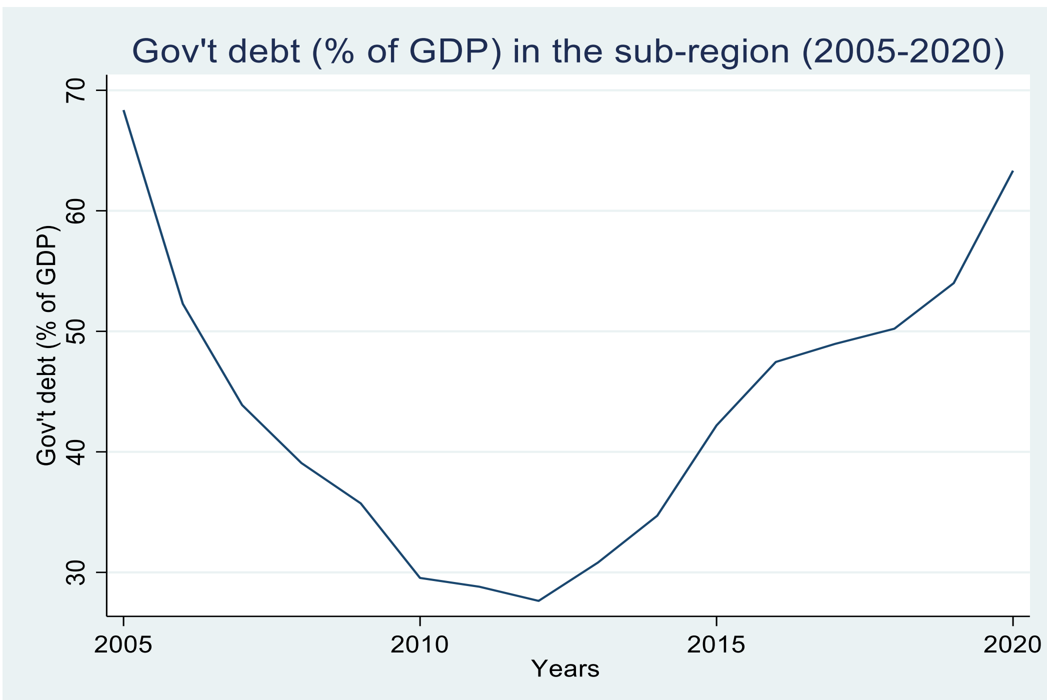

Figure 2: Trend of general government debt (% of GDP) in the sub-region (2005-2020)

Source: IMF

Figure 2 shows the graphical trend of public debt from 2005 to 2020 in the sub-region.

The surge in public debt accumulation in the 1980s led to debt difficulty, causing payment challenges in the 1990s (Ye & Guo, 2024). In the mid-1990s, the World Bank and the IMF focused on improving the debt portfolios of most developing countries. This gave 30 SSA countries an opportunity for debt reduction via the HIPC program and the multilateral debt relief initiative (MDRI) of the early 2000s (Gevorkyan & Kvangraven, 2016). These initiatives reduced the median total government debt (% of GDP) from 66% in 2000 to 24% in 2008 (IMF, 2023a). However, the debt relief programs and increased economic growth allowed new borrowing causing an increase in both internal and external government debt (Atingi-Ego *et al*., 2021). Due to the growing debt levels in the sub-region, debt servicing has reached its highest level, more than ever in the region's history, causing a strain on the fiscal space for Africa (Ekeruche, 2022). Seven of the 11 countries found to be debt distressed based on the Debt Sustainability Analysis(DSA) by IMF and World Bank in 2023 are from SSA (Were, 2024). Governments are now assigning twice as many revenues to meet payment obligations, decreasing the funds accessible to sustainable development initiatives such as climate change mitigation (United Nations Trade and Development, 2024).

There have been two contrasting arguments regarding the role of government borrowing on environmental performance. First, contractionary fiscal policies including subsidy removal, cuts in eco-friendly programmes expenditure, and debt repayment prioritisation often implemented to reduce public debt in periods of higher debt may reduce the fiscal capacity needed for green investment and implementation of strict environmental policies (Carnazza, Renström & Spataro, 2023 and Engel, 2023). The other argument is that sovereign debt can increase green investment and eco-friendly projects, which may improve environmental quality. Wang *et al*. (2021), Hashemizadeh *et al.* (2021), and Akam *et al.* (2021) hold that financing clean energy technologies is expensive, and government debt is a tool that could be used to finance these eco-friendly technologies.

In addition, fiscal policies affect how governments manage natural resources (Neumayer, 2005). Natural resources often serve as important sources of foreign exchange for many governments, particularly in Africa, where resource exports provide a means for debt service (Venables, 2016). For instance, in Ghana, the extraction sector accounted for approximately 15% of total government revenue and 67% of exports in 2020. Similarly, in Angola, the Extractive Industry Transparency Initiative (EITI) Report (2021) hinted that approximately 28% of external debt servicing was fulfilled via the shipment of crude oil, while the entire extractive sector contributed 39% of government revenue and 84% of total exports.

The debt resource hypothesis argues that the excessive exploitation of natural resources in developing countries is debt-driven (Gonzalez-Redin, Polhill, Dawson, Hill & Gordon, 2018). This is because the higher indebtedness of developing countries triggers increased utilisation of natural resources to service their debt obligation and, more so, unsustainable use of their environment (Neumayer, 2005). Danquah, Osei- owusu and Towa (2022) asserted that the need to extract and export raw materials tends to rise during high debts in resource-dependent countries like many in Sub-Saharan Africa. The authors further argued that raw material extraction for export tends to rise in the bid for most African countries to repay their debt using revenue from minerals such as gold, oil, and diamonds. This comes with a heavy environmental burden. In order to examine this dynamic, the study used material footprint as a proxy for natural resource extraction. Material footprint provides a detailed measure of the total raw materials extracted to support production and consumption (Danquah *et al.*, 2022). The material footprint is an indication of the pressures placed on the ecosystem to aid economic improvement and meet people's material demands (United Nations, 2019).

Statement of the Problem

The role of fiscal policy in shaping environmental outcomes is receiving attention in research and policy discourse. However, the issue has been less explored in SSA. Most of the existing studies, including Zhao and Liu (2022), Qi *et al*. (2022), Boly *et al*. (2019), Bese *et al.* (2020), and Li *et al.* (2022) have concentrated on regions outside SSA. The only two studies that include a few African countries are Akam *et al.* (2021) and Faroq *et al.* (2023). Meanwhile, SSA countries are grappling with indebtedness and are simultaneously vulnerable to poor environmental conditions (Africa Natural Resources Management and Investment Centre, 2022). Therefore, paying less attention to the issue in the region leaves a huge gap in the literature.

Aside from the less attention, existing literature, including the two studies that include the SSA samples, use single greenhouse gas indicators, such as CO_2 emissions, Nitrous Oxide (N_2O), and Methane (CH_4), as a proxy for environmental quality. Illuminating as they may be, these indicators ignore other environmental stresses, including land degradation, such as clearing land for agriculture, livestock grazing, wood fuels for cooking, and water pollution, which are prevalent in SSA (Africa Natural Resource Management and Investment Centre, 2022). Environmental quality is a broader phenomenon, and the most suitable measure must include multiple indicators (Salahuddin *et al.*, 2020). This study fills these gaps by computing a composite index of 40 environmental indicators capturing the key aspects of the environment.

Another gap in the existing literature is that the pathway through which debt affects environmental quality is missing. Fiscal behaviours do not operate in a vacuum, they operate through human action to produce an economic outcome. In this study, it is argued that public debt may force nations to exert pressure on natural resource extraction which may degrade the environment. Therefore, failing to examine the pathways through which fiscal policy can influence economic decisions and behaviours that affect the environment undermines the design of well-targeted policy actions that can address the issue. Furthermore, most of the existing literature has relied on the assumption of the linear nexus between government borrowing and environmental performance. However, the extensive literature documents that fiscal behaviour can have a non-linear effect. Such dimension, unfortunately, has been largely overlooked in debt-environment literature.

Finally, with SDGs 13 and 15, nations are enjoined to undertake "climate actions" and preserve "life on land." Thus, despite the fiscal burden placed on nations, there is increasing attention and a call to ratify regional green agreements and pacts as a demonstration of commitments to preserve the environment. The legitimate question then borders the extent to which such "green commitments" can help dilute the adverse impacts of debt on environmental quality. Exploring this interaction sheds light on whether green commitment can safeguard against environmental destruction amid fiscal pressure. However, this question has yet to receive empirical attention.

Purpose of the Study

The study examines the interaction between green commitments and public debt and how environmental quality performance is affected in Sub–Saharan Africa. Specific objectives are

1. estimate the effects of public debt on environmental quality performance in Sub-Saharan Africa.
2. estimate the threshold at which the effect of public debt on environmental quality becomes non-linear in Sub-Saharan Africa.
3. examine the mediating role of natural resource extraction in the relationship between public debt and environmental quality in Sub-Saharan Africa

4. estimate the extent to which commitments to regional green agreements moderate the effect of public debt on environmental quality in Sub-Saharan Africa

Research Hypothesis

1. H_0: Public debt does not significantly affect environmental quality performance in SSA.

   H_1: Public debt has a significant effect on environmental quality performance in SSA.

2. H_0: There is no significant non-linear relationship between public debt and environmental quality in SSA.

   H_1: There is a significant non-linear relationship between public debt and environmental quality in SSA

3. H_0: Natural resource extraction does not significantly mediate the relationship between public debt and environmental quality in SSA.

   H_1: Natural resource extraction significantly mediates the link between public debt and environmental quality in SSA.

4. H_0: Commitment to regional green agreements does not significantly moderate the public debt-environment relationship in SSA.

   H_1: Commitment to regional green agreement significantly moderates the public debt-environment relationship in SSA.

Definition of Environmental Quality

Environmental quality refers to the condition of natural resources and ecosystems and reflects their ability to support life and maintain sustainability. It encompasses factors such as climate change mitigation, water purity, biodiversity richness, and the extent of pollution (Environmental Performance Index, 2022). Carbon emissions, water contamination levels, deforestation rates, and species richness are measurable indicators. A high environmental quality suggests minimal human impact and balanced resource use.

Significance of the Study

This study deepens the evolving field that discusses the nexus between government borrowing and environmental outcomes and introduces the concept of green commitment in the discussion. The study provides an understanding of how rising government debt may induce excessive natural resource extraction, potentially harming the environment. The study highlights the ideal debt level that balances economic progress with ecological improvement in the subregion.

The study’s conclusions are essential to policymakers, providing policy directions and recommendations and stretching the necessity of including environmental concerns in discussions around debt sustainability in SSA countries. The study further highlights the significance of regional green agreements in improving environmental performance.

Delimitations of the Study

The interaction between green commitment and public debt's effect on environmental quality in 37 SSA countries from 2007 to 2020 was examined.

Variables used in the study are the Environmental Performance Index, General Government Debt, External Debt, Material Footprint, Green Commitment, Renewable Energy Consumption, Economic Growth, Industrialization, Agriculture, Forest Area, Foreign Direct Investment and Urbanization. Due to data availability, other relevant variables, including Domestic Debt, IMF Fiscal Rule, Net Trade and Environmental Policy Stringency, were excluded from the studies.

Limitations of the Study

The key limitation of the study is data availability for some countries in the region. This made the researcher forgo eleven countries from the studies. Despite the study's flaws, the results and conclusions are relevant and consistent.

Organisation of the Study

The research is organised into 5 distinct chapters. The introduction provides context and outlines the research problem, states objectives and hypotheses, and the scope and limitations of the study. The literature review examines theoretical and empirical literature, explores factors influencing environmental quality and presents a conceptual framework. The third chapter offers a comprehensive description of the research methods employed. The fourth chapter presents the key findings and estimation outputs. The final chapter summarizes outcomes, concludes and proposes policy recommendations.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This section reviews related theoretical and empirical scholarly works on the topic. The empirical review of other determinants of environmental quality and the conceptual framework that provides visual connections between variables are also presented in this section.

Theoretical Review

This section discussed various theories related to government debt and environmental quality.

Debt Overhang Theory

The concept of debt overhang has been extensively utilised, particularly in economic and financial research, to elucidate the impact of rising debt in both micro and macro contexts. In finance, the debt overhang theory is credited to Stewart Myers' seminal 1977 paper, "Determinant of Cooperate Borrowing." Myers (1977) posits that increased debt levels create a disincentive for investments, as future returns from such investments will likely benefit existing creditors rather than entities or new investors. Essentially, this theory proposes that companies with substantial debt burdens forgo new investment opportunities, even when these investments are advantageous because of their existing debt obligations.

Although initially applied in corporate finance, debt overhang theory was later adapted by Krugman (1988) and Sachs (1989) to address macroeconomic issues, particularly sovereign debt challenges in developing nations. They characterised debt overhang as a condition where a nation's existing or inherited debt is so substantial that creditors doubt the nation's capacity to repay fully. This theory suggests that investors anticipate potential taxes on their returns when a country struggles to meet its debt obligations, resulting in decreased investments. Over time, researchers have examined the implications of debt overhang theory and broadened its application to explain sluggish economic growth and reduced investment across various sectors, including environmental conservation.

Debt overhang theory elucidates the connection between public debt and environmental quality. Although this theory primarily examines how excessive debt affects a firm's investment, it can be applied to explain how a nation's excessive borrowing affects its capacity to invest in environmental protection. Nations grappling with debt overhangs prioritise debt management, often resulting in decisions that favour cost-cutting measures, including reduced spending on environmental protection. Moreover, when a country's debt reaches unsustainable levels, the resources dedicated to servicing existing debt limit the funds available for new initiatives such as green technology, sustainable resource management, and efforts to reduce climate impacts (Safiullah *et al*., 2024; Shaari *et al*., 2024). This theory offers a compelling explanation of underinvestment in debt-burdened entities. However, detractors argue that this theory may oversimplify intricate economic relationships and neglect other factors influencing investment decisions.

The Environmental Kuznets Curve (EKC)

In his 1955 paper "Economic Growth and Income Inequality," Kuznets examined the connection between income disparity and economic growth, discovering an inverted U-shaped relationship. He proposed that as economic development progresses, income inequality increases reach a "turning point," and subsequently decrease. This concept is referred to as the Kuznets Curve Hypothesis. In the 1990s environmental pollution became a focal point of research. Grossman and Krueger (1995) identified a similar inverted U-shaped association between economic growth and environmental pollution, now known as the EKC hypothesis. This hypothesis has since become a crucial theoretical framework for discussing environmental conditions.

The hypothesis is typically split into two eras of economic expansion: early and advanced phases. The initial stage is characterised by declining environmental quality due to pre-industrial economic activities, particularly the intensive use of natural resources (Panayotou, 1993; Sarkodie & Strezov, 2018). According to Dasgupta (2002), the early stage features lenient environmental policies, leading to environmental degradation. Conversely, the later phase, or post-industrial economy, is associated with improved environmental quality resulting from adopting green technologies and investments (Kaika & Zervas, 2013). Leal and Marques (2022) opined that this stage is marked by increased societal environmental awareness, leading to proactive institutions and stringent environmental policies. Additionally, higher income levels in the later stages result in a greater willingness to fund environmentally friendly projects. The hypothesis reveals an inverted U-shaped association between income and environmental degradation, with environmental pollution rising in poorer nations and dropping as nations become wealthier.

Research on public debt often explores its nonlinear relationship with various economic and social indicators. The EKC hypothesis is valuable in understanding the possible non-linear association between debt and the environment. During periods of lower debt, governments can generally balance economic development and environmental protection (Li, Huang & Du, 2022). At this stage, pressure on natural resources is relatively low, and environmental preservation policies may be more effective. However, when debt reaches a certain threshold, governments may prioritise debt repayment and excessive resource extraction while neglecting environmental regulations (Alhassan & Kwakwa, 2022). Critics of the EKC theory argue that it may oversimplify the determinants of ecological impact by focusing solely on economic factors and disregarding political and social dynamics (Kaika & Zervas, 2013). Furthermore, the hypothesis remains empirically contested, particularly in developing economies undergoing structural transformation (Husnain, 2021).

Porter Hypothesis

Michael Porter questioned the traditional economic view on environmental regulation in 1991. The traditional perspective, grounded in neoclassical economics, viewed environmental regulations as detrimental to business performance and profitability (Porter, 1991). This view held that strict environmental policies imposed costs on companies, potentially undermining their competitive edge. Environmental taxes, green technology, and technological standards were seen as forcing businesses to allocate resources to pollution reduction, which might not be considered productive from a business standpoint (Ambec *et al*., 2013). Porter, however, proposed that pollution was akin to resource inefficiencies and that controlling pollution could lead to more effective and sustainable resource utilisation (Jaffe & Palmer, 1997). He argues that thoughtfully crafted environmental protection policies could foster innovation and offset regulatory costs. This concept, extensively documented in academic literature over the past three decades, became known as the Porter Hypothesis.

The theory was initially introduced by Michael Porter in his 1991 article "America's Green Strategy" and further developed with Claas Van der Linde in 1995. Its core premise was that properly designed strict environmental regulations could stimulate innovation and drive economic and environmental performance (Porter & Linde, 1995; Ramanathan, 2017). Subsequent research has identified various interpretations of the hypothesis: the "weak" version suggests that regulations can drive environmental innovation; the "narrow version" posits that flexible environmental regulations are more effective at encouraging innovation; and the "strong" version asserts that such innovations can completely offset compliance costs, potentially resulting in net economic benefits (Jaffe & Palmer, 1997).

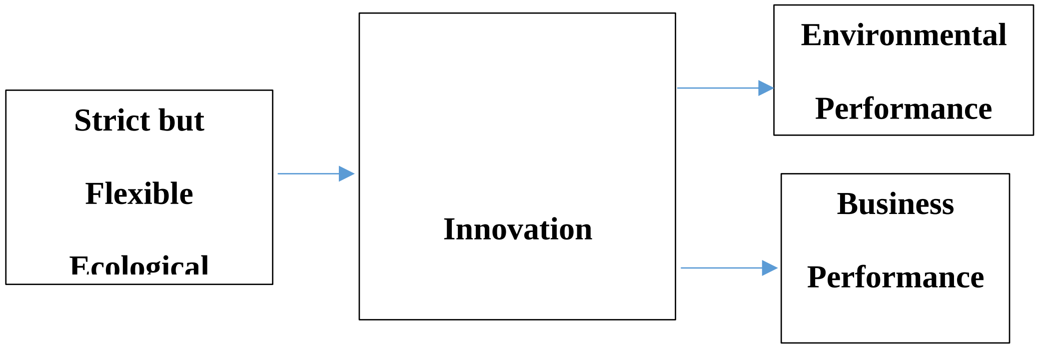

Figure 3: Schematic Representation of the Porters Hypothesis

Source: Ambec *et al.*, (2010)

While the hypothesis primarily addresses the effect of ecological laws on innovation and market competitiveness, it can be applied to elucidate the role of green commitment in the interplay between government debt and environmental quality. Green commitment is seen as a strict environmental regulation indicator which compels governments to formulate strict environmental rules. This may lead to green innovations that can improve environmental performance. Green commitment may moderate the debt-environment relationship and foster innovative practices that improve environmental quality, even in high public debt challenges.

Debt Resource Hypothesis

The debt resource hypothesis investigates the link between high indebtedness and the increased resource exploitation (Dension *et al*., 2009). The theory explains how fiscal pressures driven by high public debt compel governments to prioritise short-term revenue generation through intensive resource extraction (Neumayer, 2005). The hypothesis is rooted in the broader Debt Overhang hypothesis and the theory explains the possible tradeoff between long-term environmental performance and short-term revenue generation for debt servicing (Ampofo *et al*., 2021)

Historically, the theory gained popularity in resource-rich developing economies. The hypothesis aligns with the initial phase of the EKC, where ecological standards decline with increased economic pressure. The debt resource hypothesis provides a compelling case against environmental exploitation driven by higher indebtedness.

Critics of the hypothesis highlight its oversimplification, arguing that governance quality, institutional capacity, and external factors like global commodity prices play significant roles in resource exploitation.

Empirical Review

Several scholarly works have been carried out on the relationship between government borrowing and the environment on the cross-country and individual-country levels. The study reviewed existing literature and research works in this section.

Boly *et al.* (2019) researched the tradeoff between public debt and environmental debt. The researchers used CO_2 emissions as an indicator of environmental debt and gross public debt from the IMF Historical Public Finance database. The researchers employed the dynamic fixed effect estimator and pooled mean group estimator on 22 countries from 1990-2011. The authors discovered that there will be a 74% rise in emissions when there is a 100-unit increase in debt. Conversely, the study showed that in the short run, public debt and CO_2 move in the opposite direction. In their findings, an increase in debt by 100 units incites CO_2 emissions to be reduced by 17%.

Akam *et al*. (2021) examined the interplay between external debt and environmental degradation in HIPC Countries. The authors conducted this research by sampling 33 HIPC countries between 1990 -2015. The study employed the Dynamic common correlated mean group, common correlated mean group and Augmented mean group. The study found external debt stock to be insignificant. Hence, external debt does not affect CO_2 emissions. The authors attributed the outcome to the sluggish progress of the energy transition and low demand for environmentally friendly technologies in pro-poor countries. In a similar study by selected emerging countries, Zeraibi *et al*. (2024) analysed the nexus of public debt and CO_2 emissions controlling for renewable electricity and economic growth. The authors discovered a statistically significant relationship between public debt and CO_2, and public debt reduces CO_2 emissions. Their finding sharply contrasts with Akam, Owolabi and Nathaniel's (2021) findings.

To shed light on the drivers of CO_2, Zhao and Liu (2022) focused on the debt perspective and demonstrated how debt can affect $C0_2$ emissions. The authors used a dataset of 50 countries from 2001 to 2019. The authors categorised the countries into developed and emerging countries and conducted the analysis based on three different periods. 2001 - 2019, the whole study period, 2001-2007(before 2008), and 2008-2019 (after 2008). The rationale for the split in the period is to account for the global financial crises in 2008. The results from the study indicate that during the pre-crisis, debt generated a slight increase in CO_2 in developed economies and then contributed to a reduction in CO_2 after the crises. The relationship between debt and CO_2 for emerging economies was positive in both regimes. The authors used the Logarithmic Mean Divisia Index (LMDI) approach to analyse the various determinants of CO_2.

A cross-country study by Farooq *et al*. (2023) examined the relationship between public debt and environmental degradation in 43 Organization of Islamic Countries (OIC). The study took into account the influence of institutional quality. The research objectives were achieved using the two-step system GMM. To measure environmental degradation, the researchers used five proxies, including CO_2, N_2O, CH_4, ecological footprint, and deforestation. Additionally, the researchers categorised the countries into low-income, average-income, and high-income OIC countries. According to the study, public debt has a considerable negative effect on the environment in low and average-income OIC countries, while it improves the conditions of the environment in wealthy OIC countries. In addition, the study demonstrated that institutional quality can mitigate the adverse effects of public debt on various measures of environmental degradation. The study used a couple of environmental pollutants. However, these pollutants do not capture a wide range of environmental dimensions. Ecological footprint is related to the degree of environmental consumption rather than ecological damage.

To assess whether public debt is environmentally friendly, Carnazza *et al*. (2023) analysed the response of the European Union (EU) fiscal framework on environmental quality within 27 EU countries. The study examined the impact of two distinct policy measures on CO_2 emissions. The authors employed the implicit tax rate of energy (ITRE) as an indicator for energy tax and analysed its effect on CO_2 emissions. Additionally, debt-to-GDP and the magnitude of the strictness of the European economic fiscal framework were interacted. This research was conducted in 27 EU countries with panel data from 1995 to 2021. Using the generalised least squared fixed effect model, the study established that ITRE reduces $C0_2$ emissions. On the contrary, the study unveiled that amid a strict fiscal framework, public debt increases CO_2 emissions.

Carrera and Vega (2024) used $C0_2$ emissions to measure greenhouse gas emissions. They conducted a cross-country analysis of how external borrowing can influence greenhouse gas emissions across 78 emerging and developing nations from 1990-2015. The study used international liquidity shocks as an instrumental variable for external debt to solve the endogeneity problem. The study discovered an insignificant connection between governments' external borrowing and greenhouse gas emissions. However, after accounting for the possibility of endogeneity, the result revealed a positive and significant nexus between external debt and GHG emissions.

In a country-specific analysis, Bese *et al.* (2021) examined the effect of external debt on emissions in China. The authors employed data from 1978 to 2014. The researchers utilised the non-linear and linear ARDL model to examine the symmetric and asymmetric nexus among the variables. The study revealed a positive link between external debt and CO_2 in linear and nonlinear ARDL. Contrary to their findings, a study conducted by Katircioglu and Celebi (2018) found that external debt does not significantly influence CO_2 emissions. The authors employed data spanning 53 years from Turkey. The authors augmented the EKC theory with Energy consumption and external debt and used the Johansen methodology to achieve the objectives.

Using an FMOLS model and annual time series data from 1971 to 2018, Alhassan and Kwakwa (2022) analysed the impact of resource extraction and public debt on environmental sustainability in Ghana. The results indicated that the earlier stages of debt are not detrimental to the environment, but as debt exceeds a certain point, it becomes harmful to the ecosystem. This results in a U-shaped relationship. The studies did not inform us of the particular debt levels that will cause the change in the relationship between the variables. This finding is similar to Li *et al.* (2022) work based on their analysis of 30 provinces in China from 2011 to 2019. The researchers revealed a nonlinear nexus between local government debt and environmental pollution in China. The study used an ordinary panel model and spatial effect analysis to arrive at their conclusion.

In a recent study in Nigeria, Ezenekwe *et al*. (2023) assessed whether public debt and agriculture reduce environmental pollution. The authors used time series data from 1981 to 2021. The study critiqued using CO_2 emissions to capture environmental degradation and used ecological footprints because it provides a comprehensive measure of pollution. Also, the researchers used external and domestic debt instead of the general government debt and analysed their effect on the environment. Using DOLS and the FMOLS models, the study revealed that domestic and external debt improve environmental quality in Nigeria.

Onuoha *et al.* (2023) investigated the nexus between public debt and renewable energy consumption and how governance quality moderates the relationship in SSA. The study used the feasible generalised least square model for 29 SSA countries from 1996 to 2020. The study found public debt to positively affect renewable energy consumption in the countries under the study. Using a similar estimation technique in a study of 20 emerging economies, Hashemizadeh *et al.* (2021) showed that an increase in public debt causes a reduction in renewable energy consumption among the selected countries. The study's finding sharply contrasts with the study by (Onuoha *et al*., 2023). The differences in the results may be due to the locational dynamics.

To conclude, although studies have linked government debt to environmental performance. There have been contrasting findings. Also, the literature has received little attention in SSA. Furthermore, indicators used to capture the environment need to be more comprehensive to encapsulate all aspects of the environment. In addition, most literature on fiscal behaviour estimates the point at which the initial relationship between fiscal policy and the outcome variable will change. This is important for policy implications as government borrowing might not be harmful below a particular value, but it might be detrimental beyond that level. This specific threshold value has yet to be estimated in SSA. In addition, the possible path through which government borrowing can influence the environment is missing. Finally, the role of green commitment in the interplay between government borrowing and the environment has not been explored in the literature. This study provides solutions to the gaps that have been identified in the literature.

Other Determinants of Environmental Quality

Foreign Direct Investment (FDI) and Environmental Quality

FDI influences environmental conditions in a couple of ways. Neumayer and Oladi (2015) analysed how FDI and ecological aid disbursements induce environmental pollution. The authors stressed that FDI may induce pollution depending on two factors. The sector of the economy that FDI is directed to and the type of machines used in these industries. They explained that FDI inflows targeted at the manufacturing sectors are expected to induce pollution. Also, they posited that clean technology is environmentally friendly; hence, FDI geared towards production processes that rely on green technology would be favourable to the ecosystem. The study found FDI to be environmentally friendly within the selected developing countries. Similarly, Demena and Afesorgbor (2020) discovered proof of a negative relationship between FDI and environmental pollution after controlling for heterogeneity in their studies. The study performed a meta-analysis on the nexus between FDI and the environment using 65 studies that produce 1006 elasticities.

A study by Adeel-Farooq *et al.* (2021) argued that FDI can be detrimental or favourable to a host country depending on the stringent environmental regulations in the sourced country. Using the fixed effect, GMM estimator and random effect, the researchers found that FDI from developing economies is detrimental to the environment. In contrast, the study's findings revealed that FDI from developed nations enhances the environmental outcomes of the recipient countries.

Economic Growth, Renewable Energy Consumption and Environmental Quality

The interplay between economic growth and environmental quality has been widely documented since the inception of the EKC hypothesis. The argument has increasingly suggested that economic improvement leads to poor environmental outcomes, while others believe that higher income increases the demand for better environmental conditions. Adu and Taylor (2017) examined the influence of economic growth on environmental pollution and tested for the EKC hypothesis. The researchers used a dataset covering 1970 to 2013 for selected countries in West Africa, within similar income brackets. This study discovered that economic growth degrades the ecosystem in the short run. However, an insignificant relationship is identified in the long run. The authors argued that an inverted U-shaped relationship cannot explain the growth environment nexus within the selected countries. Likewise, Özokcu and Özdemir (2017) highlight an unsupported EKC hypothesis in their studies. The study examined the following relationships: per capita income, CO_2 emissions, per capita income, energy use, and CO_2 in 26 OECD and 52 emerging economies between 1980 and 2010. After using a fixed effects model and a Driscoll-Kraay standard error, the study discovered an N-shaped Curve and an inverted N-shaped curve.

To assess the relationship between renewable energy consumption and CO2 emissions, Salem et al. (2021) identified ten leading carbon-generating countries as their sample targets. This study examined the nonlinear relationship between CO*2* emissions and renewable energy consumption and its three components: wind, solar, and hydropower. A Pooled Mean Group (PGM) model was employed in this study. It was revealed that hydropower exhibits an inverted U-shaped relationship, while wind and solar energy consumption have a U-shaped relationship. Another study conducted in oil-rich countries by Mukhtarov et al. (2022) used the DOLS method to examine the impact of renewable energy consumption on CO_2 emissions in Azerbaijan. The researcher used data from 1993 to 2019 and found an inverse relationship between renewable energy consumption and CO_2 emissions.

Agriculture Value-added and Environmental Quality

Agriculture and the natural environment are closely related. Agriculture sector activities, including livestock rearing, rice farming, and fertiliser applications, contribute to greenhouse gas emissions. To provide an empirical answer to whether agricultural value-added triggers environmental pollution in Azerbaijan, Gurbuz *et al*. (2021) used ARDL to establish an association between agricultural production and CO_2 emissions. The authors employed annual data spanning 1992 to 2014. The researchers found agriculture production and CO_2 emissions to have an inverse relationship. This means an increase in added agricultural value improves environmental performance. A similar study by Agboola and Bekun (2019) explored the impact of farming activities on environmental degradation in Nigeria. Utilising annual data from 1981-2014 and the ARDL model, the researchers examined the interplay between agriculture and CO_2. The findings revealed a positive link, indicating how agriculture intensification in the country leads to increased CO_2 emissions, contradicting the findings of Gurbuz, Nesirov and Ozkan (2020). In addition, a cross-country analysis by Adedoyin *et al*. (2021) examined whether agricultural improvement stimulates environmental pollution in seven emerging countries employing econometric techniques. The researcher found agricultural advancement to have negative consequences on the environment.

Urbanisation, Forest Area and Environmental Quality

Urbanisation remains a primary approach adopted by communities to enhance their living conditions. Many underdeveloped nations experience a high rate of urbanisation in cities because of the assurance of higher income opportunities. Sasana *et al*. (2019) shed light on the repercussions of urbanisation on ecological conditions in Indonesia. This study employed OLS for the period 1990–2016. The authors highlighted that urbanisation had a statistically direct effect on emissions. Also, in an attempt to establish the linkage between urbanisation and CO_2, Wang *et al*. (2016) performed a Granger causality test for BRICS countries within the periods of 1985 and 2014. The research revealed a long-run cointegration link between urbanisation and CO_2.

Global climate change has emerged as a significant concern, primarily due to greenhouse gas emissions, with CO_2 being the most predominant factor. Forest areas play an increasingly vital role in addressing climate change by capturing atmospheric CO_2 (Raihan *et al.*, 2021). A study by Raihan (2023) examined the determinants of CO_2 emission in the Philippines. The study employed the ARDL and DOLS approaches and annual data for 32 years to examine the determinants of CO_2. The study found forest areas to reduce CO_2 emissions.

Industrial Value Added and Environmental Quality

The environmental impact of industrialisation has been widely studied in literature. The EKC hypothesis posits that as an economy transitions from an agrarian society into an industrial society, the latter initially contributes rapidly to environmental deterioration since industrialisation is linked to energy consumption but might reduce environmental pollution once a certain growth level is obtained. A time series analysis by Musah and Yakubu (2022) explored industrialisation and ecological sustainability in Ghana using the FMOLS model. The researchers used data from 1970 to 2017 to examine the environmental impact of industrialisation. The study revealed an inverse relationship between industrialisation and ecological footprint. This stipulates that the increase in industrialisation is environmentally friendly in Ghana.

A cross-country analysis in SSA by Nkemgha *et al.* (2024) linked industrialisation and the environment and examined how stringent environmental standards moderate this relationship. The authors gathered panel data from 24 countries in SSA and data covering the period of 2000-2020. After applying the system GMM estimation technique, the researchers found industrialisation to impede environmental performance in the selected countries.

Conceptual Framework

The conceptual framework used in this study provides a visual representation that explains the central concept and relationship between government borrowing and environmental quality. In the diagram, public debt influences environmental quality through resource extraction. Resource extraction is a possible pathway through which debt can affect the environment in the Sub-region. This is motivated by the debt resource hypothesis. However, the extent to which government borrowing affects environmental outcomes through resource extraction depends on the country's government's commitment to protecting the environment. Green commitment compels governments to enforce stringent environmental rules that influence environmental quality and weakens the impact of government borrowing.

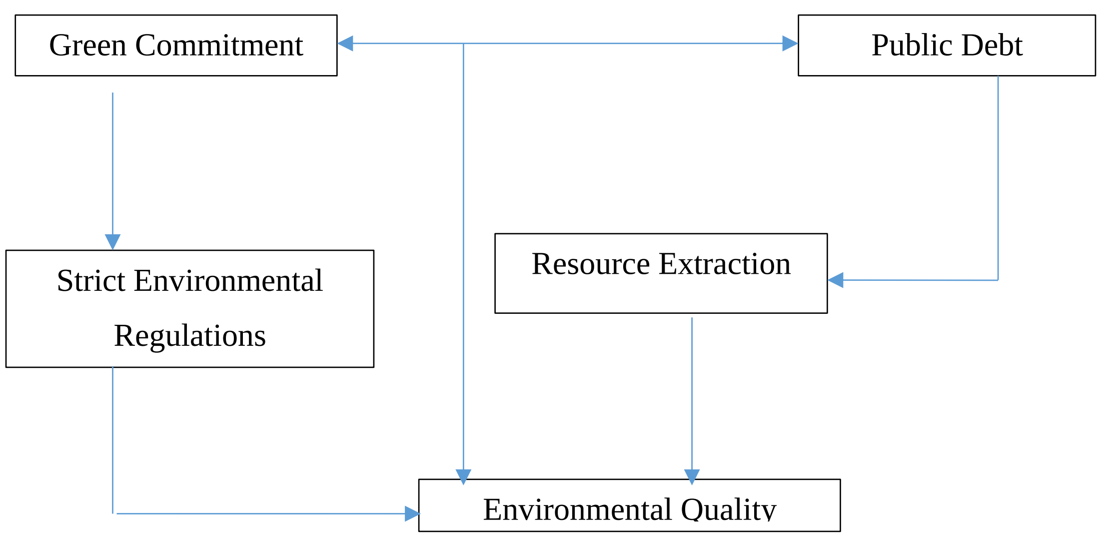

Figure 4: Relationship between Public Debt, Natural Resource Extraction, Green Commitment and Environmental Quality.

Source: Author’s own construct, 2025.

Chapter Summary

This section presented the conceptual framework and the empirical and theoretical literature. The theories considered are the Debt Overhang Theory, EKC Hypothesis, Porter Hypothesis, and Debt Resource Hypothesis. Some of the flaws of the theory are its being overly simplified and not applicable to developing economies undergoing structural transformation. The chapter identified research gaps in the current research including, locational gaps and knowledge gaps. Also, the study highlighted that indicators used to capture the environment need to be more comprehensive to encapsulate all aspects of the environment.

CHAPTER THREE

RESEARCH METHODS

Introduction

This chapter outlines the research design utilised in the study. This section offers a comprehensive explanation of the empirical specification that captures the research objectives. Additionally, the chapter defines the variables, their measurements and justifications, sources, and descriptions. The econometric technique and diagnostic analysis are explained.

Research Approach and Design

In research, it is necessary to outline the steps in which the research objectives are to be obtained. A crucial step in this process is developing the research design, which entails examining and determining the appropriate methods and techniques for the study (Rashid *et al*., 2019). The quantitative research approach and positivist research philosophy, in particular the longitudinal design are utilized. Longitudinal studies allow repeated data collection from the same participants over extended periods.

Research design can be broadly categorised as quantitative or qualitative. Quantitative research focuses on collecting and analysing numerical data to verify and quantify the relationships and trends among phenomena (Watson, 2015). Quantitative research is typically employed when the primary aim is to explain, describe, or explore an occurrence (Leavy, 2022). The research employed a quantitative approach to data analysis, characterized by a deductive nature, where hypothesis-testing results lead to broader inferences about population characteristics.

Model Specification

In this research, the functional form model is given by

$$EPI_{it} = f\begin{pmatrix} EPI_{i,t-1}, Pd_{it}, Urbg_{it}, Fdi_{it}, Forest_{it} \\ , Rec_{it,} Agric_{it}, Indus_{it}, Gdpg_{it}, Rat_{it} \end{pmatrix} \ldots\ldots (1)$$

Where EPI is the Environmental Performance Index used as a proxy for environmental quality, EPI_{t-1} is the lagged value of EPI and was added to control for endogeneity. Pd represents Public debt, Urbg represents Urban population growth, Fdi represents foreign direct investment, Forest represents Forest area as a percentage of land area, Gdpg is growth in gross domestic product, Agric is Agriculture, Indus represents Industrialization, and Rat represents Green commitment.

The empirical model specification follows (Akam *et al*., 2021; Carrera & Vega, 2022; and Farooq *et al*., 2023). To achieve objective 1, the empirical model is given as

$$EPI_{it} = \alpha_0 + \propto EPI_{i,t-1} + \alpha_1 Pd_{it} + \alpha_2 W_{it} + \eta_t + v_i + \varepsilon_{it} \qquad i = 1, 2, 3 \ldots 37; t = 1,2,3 \ldots 14 \qquad \ldots\ldots (2)$$

v_i, η_t and ε_{it} are country-specific unobserved effects, time-specific effects and the idiosyncratic error term respectively. W_{it} represent control variables employed in the study. The subscripts, i *and* t, denote country and period, respectively.

To achieve objective 2, this study employs the dynamic panel threshold model to estimate the particular debt levels that change the direction of the relationship. The empirical model is specified as

$EPI_{it} = \alpha_0 + \propto EPI_{i,t-1} + \alpha_1 Pd^2{}_{it} + \alpha_2 W_{it} + \eta_t + v_i + \varepsilon_{it}$ i = 1, 2, 3 …37; t = 1,2,3...14 ……………………………………(3) $Pd^2{}_{it}$ is the squared of public debt.

The third objective seeks to determine whether debt will affect environmental quality by affecting the level of natural resource extraction. This study introduced two variables: external debt and raw material footprint. The external debt replaces the general public debt, and the raw material footprint is used as a mediator to measure resource extraction. This analysis highlights how external pressures from the region's high dependence on foreign borrowing could influence the region's ecosystem through resource extraction. External debt poses a unique challenge, as its pressures can compel countries to relax ecological regulations to attract investment in the resource extraction sector. The following are the mediation equations which follow the work of (Baron & Kenny, 1986).

$EPI_{it} = \beta_0 + \gamma EPI_{i,t-1} + \beta_1 EXD_{it} + \beta_j W_{it} + \eta_t + v_i + \varepsilon_{it}$ $i = 1, 2, 3 \ldots 37;\ t\ 1,2,3 \ldots 14$ ……………………………………………………(4)

$lnMF_{it} = \beta_0 + \gamma_0 lnMF_{i,t-1} + \delta_1 EXD_{it} + \delta_j W_{it} + \eta_t + v_i + \varepsilon_{it}$ $i = 1, 2, 3 \ldots 37;\ t = 1,2,3 \ldots 14$ ……………………………………………………………(5)

$$EPI_{i,t} = \beta_0 + \gamma_1 EPI_{i,t-1} + \rho_1 EXD_{it} + \rho_2 lnMF_{it} + \beta_j W_{it} + \eta_t + v_i + \varepsilon_{it} \quad \text{i} = 1,2,3 \ldots 37; \text{ t} = 1,2,3 \ldots 14 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

In equation (4), $lnMF_{it}$ is the log of material footprint, which is used as a measure for natural resource extraction, EXD_{it} is external debt. δ_1 represents the effect of external debt on resource extraction. If external debt affects environmental quality, that is, if β_1 is significant in equation (4), then we will proceed to estimate equation (5) and equation (6). If δ_1 in equation (5) and ρ_2 in equation (6) are both significant, then external debt affects environmental quality through natural resource extraction, and the intermediary effect could be calculated by multiplying ρ_2 *and* δ_1. Resource extraction is a partial mediating variable if ρ_1 is still significant, but if ρ_1 is insignificant, then resource extraction is a complete mediating variable. ln represents natural logarithm and helps to reduce the variability of the material footprint.

To achieve the final objective, which is to estimate the extent to which green commitments moderate the public debt and environmental quality relationship in SSA, the empirical model is specified as

$$EPI_{it} = \alpha_0 + \propto EPI_{i,t-1} + \alpha_1 Pd_{it} + \alpha_2 Rat_{it} + \alpha_3 Rat * Pd_{it} + \alpha_4 W_{it} + \eta_t + v_i + \varepsilon_{it} \quad \text{i} = 1, 2, 3 \ldots 37; \text{t} = 1,2,3 \ldots 14 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Data Type and Source

The study used panel data spanning from 2007 to 2020. The panel data has a total of 37 Sub-Saharan African countries. The indicators employed in the study and its sources are presented in table 1.

Table 1: Measurement of Data and Sources

Variable	Measurement	Source
Environmental Quality	Index of 40 indicators	Yale Center for Environmental Law and Policy (YCELP)
Public Debt	General government debt (% of GDP)	IMF
External Debt	External Debt Stock (% of GNI)	WDI
Material Footprint	Trade adjusted (Metric tons)	Global Material Flow Database
Urbanisation	Urban population growth (annual %)	WDI
Foreign Direct Investment	Net inflows of FDI (Percentage of GDP)	WDI
Renewable Energy Consumption	Renewable energy consumption as a percentage of total energy consumption (Kilograms per capita)	WDI
Agriculture	Agriculture value added(% of GDP)	WDI
Industrialisation	Industry value added (% of GDP)	WDI
Economic growth	GDP growth (annual %)	WDI
Forest Area	Forest Area (% land area)	WDI
Green Commitment		Authors

Source: Author's compilation, 2025

Variable Description, Justification and Expected Sign

In this sub-section, the definitions, the measurement and the expected signs for the variables are presented.

Dependent Variable

Environmental Quality

Environmental quality is a phenomenon that encapsulates a broad scope of environmental dimensions. Using one variable to account for all of the effects on the different aspects of the environment becomes problematic. Environmental researchers have increasingly adopted composite indexes to encapsulate a more comprehensive view of the ecosystem, allowing for a broader assessment of environmental conditions. Consistent with Noubissi *et al. (2021)* the study used the environmental performance index (EPI) as a proxy for environmental quality. This study used the index as the outcome variable. Employing the EPI to measure the quality of the environment is justified because the EPI scores provide evidence to locate which nations have been proactive and most successful in dealing with a wide range of ecosystem challenges, recognise sustainability leadership and point out countries lagging. Given this, the EPI provides countries with data to trace advancement in achieving sustainable development goals and important policy targets on ecosystem performance. The EPI score uses 40 performing environmental indicators and groups into 11 categories. These 11 categories are then grouped into 3 different target objectives. Which are climate change, ecosystem vitality and environmental health. These three categories are captured to form a country-level environmental performance indicator using comprehensive and accessible metrics. The EPI is constructed using a “distance-to-target” methodology that traces how close a nation and the global society are to achieving established environmental policy goals. The raw environmental data is then processed into indicators that rank countries on a scale ranging from 0-100, from poor to best performing. A higher score (100) indicates a perfect score and shows that a nation has successfully achieved an internationally recognised sustainability target or expects recognition for good performance. On the other hand, 0 represents the worst-performing score. Generally, the indicator is calculated using the given formula

$$Indicator\ Score = \frac{X - W}{B - W} \times 100$$

Where X represents a nation's value, B is the supposed benchmark for ideal performance, and W is the target for poor performance. The formula is such that countries with values greater than B are normalised to achieve a 100 score. Also, countries with a value lesser than W are capped to 0. The motive behind the capping is to deal with outliers, which may affect the performance of other countries' scores. The study used simple arithmetic means for all indicators to calculate the environmental performance index. The study used all 40 indicators to compute the index. The simple arithmetic mean was preferred because it can handle missing values effectively. For example, if six series in the 40 indicators have missing values, the index will still be created by computing the mean of the rest of the 34 indicators that have observations. A negative relationship between the environmental policy index and a variable indicates environmental decline. Conversely, a positive relationship suggests environmental improvement.

Main Independent Variables

a. Public Debt

General government debt is the gross debt of the general government expressed as a share of GDP. Where applicable, public debt is the summation of all accounts payable by the government. It includes government payment obligations owed to individuals and entities overseas and individuals and entities in the host country. Over time, government debt changes reflect the impact of past deficits on government finances. The literature has found contrasting outcomes between public debt and environmental quality. In one view, debt financing green projects can improve the ecosystem, while debt can impede government investment necessary to ensure a clean environment.

b. External Debt Stock

External debt is compared to gross national income (GNI) to measure the financial health of a country. The World Bank defines external debt as the debt that encompasses all money owed to foreign entities, payable in various forms such as currency, goods, or services. It comprises both long and short-term debt, International Monetary Fund credit usage, and overdue long-term borrowing costs. GNI represents the total value created by a country's residents. This comparison helps assess a nation's debt burden relative to its economic output. External debt is anticipated to have either a beneficial or detrimental influence on the environment. External debt stock (% of GNI) is another independent variable employed in the mediation analysis.

Moderating and Mediating Variable

a. Green Commitment

In 1968, the African Union (previously known as the Organization of African Unity) adopted a sustainable environmental policy called the Africa Convention on the Conservation of Nature and Natural Resources. The call for sustainable environmental management hinged on the growing demand and pressure on the natural endowments of the continent. Due to the need for a collective effort in managing shared ecosystems like river basins and forest and wildlife protection, the charter prioritises cooperation among African nations in environmental management. A dummy variable was created, assigning 1 to a country that has ratified the convention and 0 otherwise. This variable depicts a country's commitment to environmental protection through the treaty's ratification. In addition, the ratification of the framework shows the government's zeal to integrate some formal internationally recognised environmental standards. It is envisaged to have a positive association with the environment.

b. Material Footprint

Material footprint refers to the total volume of raw materials extracted to support final consumption. The study used material footprint as a proxy for natural resource extraction since material footprint directly measures natural resource usage from extraction to final consumption. A consumption-based indicator, raw material footprint (RMF) or material footprint (MF), which measures the direct and indirect raw material for domestic and trade purposes, provides a holistic measure of raw material equivalent (Schaffartzik *et al.*, 2015). The material footprint reflects how economic expansion and human consumption impact the environment. Government borrowing is expected to increase raw material footprint consumption, and raw material footprint consumption is predicted to impose pressure on the ecosystem.

Control Variables

Many factors influence the performance of the environment. Following previous studies by Carrera and Vega, 2022; and Farooq *et al*. 2023 and data availability, the study selected a couple of control variables.

Foreign Direct Investment (FDI)

According to the World Bank, FDI is the expenditure needed to get a prolonged managerial interest (voting stake of 10% or more) in an organisation or business outside the investor's home country. FDI is primarily an intercountry investment where citizens of a country invest and control a meaningful stake and management of cooperation in another country. The variable depicts the net inflows (new investment inflows minus investment outflows) recorded by indigenous countries for foreign investors, divided by GDP. A large number of literature posits that FDI is detrimental to the environment, especially when businesses may migrate to economies with loosed ecological standards. At the same time, others believe that green technological transfers induced by FDI are suitable for the host country's environment (Neumayer & Oladi, 2015). From a theoretical and empirical view, FDI's environmental impact can be positive or negative (Adeel-Farooq *et al*., 2021). Therefore, the study anticipates a direct or indirect association between FDI and environmental quality.

Renewable Energy Consumption

The World Bank defines renewable energy consumption as the fraction of clean energy in the total final energy consumption. It is expected to positively influence the environment. This is because clean energy sources such as hydropower, solar, and wind generate minor greenhouse gases (Ampomah *et al*., 2014). As the consumption of clean energy increases, the dependency on non-renewable resources declines, leading to less air and water pollution, reduced carbon emission and a more negligible ecological impact (Pata, 2021). Therefore, renewable energy consumption is environmentally friendly (Zaidi *et al*., 2018).

Urbanisation

Urbanisation refers to the general increase in the population, the movement of people from rural areas to city areas, and the industrialisation of settlements. The supposed direction of Urbanization and environmental quality is ambiguous. On one view, rapid urbanisation often leads to increased pollution, deforestation, habitat extraction, and higher energy consumption, which degrade air and water quality (Lyu *et al*., 2018). Contrary, urbanisation can improve environmental quality by promoting efficient usage of resources (Liang & Yang, 2019). For urbanisation, the study aligns with (Gasimli *et al*., 2019 and Ridzuan *et al*., 2020).

Gross Domestic Product (GDP)

GDP is the aggregate production by all residents in a country to any product taxes minus any subsidies not included in the production value. It is expressed, based on constant local currency, as the annual percentage growth rate of GDP at market prices. The study used Gross Domestic Product Growth (annual %) to measure economic growth consistent with (Al-Mulali., *et al.* 2015; Tariq *et al*., 2018). Based on the Environmental Kuznets Curve hypothesis, the researcher expects economic advancement to either increase or decrease environmental pollution.

Productive Structure

In this study, Agriculture value-added and industry value in GDP are used as the productive structure of an economy. This follows the work of (Carrera & Vega, 2022). One primary explanation of the EKC hypothesis hinges on the evolution from an agrarian economy to a production-based economy, resulting in increased pollution as the latter tends to be more pollutant than the former. This means that environmental degradation becomes obvious as industrialisation becomes rampant. The added value of agriculture includes forestry, hunting and fishing, crop cultivation, and livestock production. The added value of agriculture is expected to harm the environment. On the other hand, industrialisation value is determined by value added to the industry, including construction and manufacturing. Industrialisation is expected to negatively or positively affect the environment. The environment gets polluted through increased pollution from factories, waste disposal, and higher energy demands, often caused by reliance on fossil fuels (Perera, 2018). On the contrary, sustainable industrial practices through improved resource efficiency and the usage of environmentally friendly machines can help reduce harmful ecological destructions (Tang *et al*., 2022).

Forest Area

The World Bank defines forest area as the share of the total land area covered by forest. This measure includes natural and planted tree stands at least 5 meters tall, regardless of their productivity. It excludes trees in agricultural systems. This indicator shows the presence of forests and the lack of other dominant land uses. The definition encompasses existing forests meeting the height and coverage criteria, reforested areas expected to reach 10% canopy cover and 5-meter height, and temporarily unstocked areas due to human activity or natural events, which are anticipated to regrow. This metric helps assess forest coverage and land use patterns. For forest areas, the study follows (Carrera & Vega, 2022). It is expected to have a positive effect on environmental quality.

Estimation Procedure

To obtain the study's objectives, the problem of endogeneity was considered. The empirical literature on debt and environment, including the studies by Giovanis and Ozdamar (2022), Zenios (2022) and Boitan *et al*. (2022), prove that environmental impact affects sovereign debt, while other works show that government borrowing has an environmental impact. A dynamic model would be appropriate to solve the potential reverse causality that creates the problem of endogeneity. The dynamic panel (GMM) model proposed by Arellano and Bond (1991) is suitable for panel datasets with a large number of individual units (Countries) and a short time dimension. The generalised method of moment (GMM) estimator has several advantages, including the following;

1. It can solve endogeneity by using the dependent variable's lag.
2. Baum *et al.* (2003) argued that the GMM generates more consistent and efficient results than the IV technique when heteroscedasticity exists.
3. The GMM is also efficient when the error term is not normally distributed, an assumption required under ordinary least squared (OLS).

The first difference GMM proposed by (Arellano and Bond, 1991) is applied to equation (2) to obtain equation (8)

$$EPI_{i,t} - EPI_{i,t-1} = (\alpha_0 - \alpha_0) + \propto (EPI_{i,t-1} - EPI_{i,t-2}) + \alpha_1(Pd_{i,t} - Pd_{i,t-1}) + \alpha_2(W_{i,t} - W_{i,t-1}) + (v_i - v_i) + (\eta_t - \eta_{t-1}) + (\varepsilon_{i,t} - \varepsilon_{i,t-1})$$

i = 1, 2, 3 …37; t = 1,2,3...14 ………………………………………………………… (8)

$$EPI_{i,t} - EPI_{i,t-1} = \propto (EPI_{i,t-1} - EPI_{i,t-2}) + \alpha_1(Pd_{i,t} - Pd_{i,t-1}) + \alpha_2(W_{i,t} - W_{i,t-1}) + (\eta_t - \eta_{t-1}) + (\varepsilon_{i,t} - \varepsilon_{i,t-1})$$

i = 1, 2, 3 …37; t = 1,2,3...14 ……………………………………………………………………………….. (9)

Equation (9) could be written as

$$\Delta EPI_{i,t} = \propto (\Delta EPI_{i,t-1}) + \alpha_1(\Delta Pd_{i,t}) + \alpha_2(\Delta W_{i,t}) + \Delta\eta_t + \Delta\varepsilon_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The first difference estimator causes an endogeneity bias. This is because the new error term $(\varepsilon_{i,t} - \varepsilon_{i,t-1})$ created by differencing in Equation (9) may correlate with $(EPI_{i,t-1} - EPI_{i,t-2})$. The difference GMM solves this problem by allowing for the use of the lagged values of the independent variables as an instrument, contingent on fulfilling two-moment conditions, which are: error term does not correlate with the instrument and the independent variables are weakly exogenous

$$E[EPI_{i,t-s}, (\varepsilon_{i,t} - \varepsilon_{i,t-1})] = 0 \; for \; all \; S \geq 2: t = 3, \ldots, 14 \ldots \quad (11)$$

and

$$E[W_{i,t-s}, (\varepsilon_{i,t} - \varepsilon_{i,t-1})] = 0 \; for \; all \; S \geq 2: t = 3, \ldots, 14 \ldots \quad (12)$$

The estimation technique is the difference in GMM once the instruments satisfy the moment conditions. The difference GMM estimator has several flaws and has been critiqued by many researchers. For example, it is inefficient, particularly when the autoregressive parameter is significant and the number of times is negligible (Blundell and Bond, 1998). Also, the same researchers argued that difference GMM has weak instruments and eliminates time-invariant variables through differences. To improve the flaws of the difference GMM, a system in which the lagged levels and the lagged difference are used as instruments was proposed. This results in solid instruments and forms a system of equations known as the system GMM (Blundell & Bond, 2000). Soto (2009) found that system GMM outperforms the difference GMM in bias reduction, particularly in small samples with highly persistent series. Due to the system GMM's advantages over the difference GMMs, the study employed the system GMM to achieve efficient results.

To achieve objectives 1, 3, and 4, the study employed the system GMM, translated into equations (13) to (17).

The system GMM specification for objective one is given as

$$\Delta EPI_{i,t} = \propto (\Delta EPI_{i,t-1}) + \alpha_1(\Delta Pd_{i,t}) + \alpha_2(\Delta W_{i,t}) + \Delta\eta_t + \Delta\varepsilon_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

The system GMM specification for the mediation analysis for objective three is given as follows

$$\Delta EPI_{it} = \gamma(\Delta EPI_{i,t-1}) + \beta_1(\Delta EXD_{i,t}) + \beta_j\left(\Delta W_{i,t}\right) + \Delta\eta_t + \Delta\varepsilon_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

$$\Delta lnMF_{it} = \gamma_0(\Delta lnMF_{i,t-1}) + \delta_1(\Delta EXD_{i,t}) + \beta_j\left(\Delta W_{i,t}\right) + \Delta\eta_t + \Delta\varepsilon_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

$$\Delta EPI_{it} = \gamma_1(\Delta EPI_{i,t-1}) + \rho_1(\Delta EXD_{i,t}) + \rho_2(\Delta lnMF_{i,t}) + \beta_j\left(\Delta W_{i,t}\right) + \Delta\eta_t + \Delta\varepsilon_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

The system GMM specification for objective four is given as

$$\Delta EPI_{i,t} = \propto (\Delta EPI_{i,t-1}) + \alpha_1(\Delta Pd_{i,t}) + \alpha_2(\Delta Rat_{i,t}) + \alpha_3(\Delta Rat_{i,t} * \Delta Pd_{i,t}) + \alpha_4(\Delta W_{i,t}) + \Delta\eta_t + \Delta\varepsilon_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Hansen (1999) panel threshold regression (PTR) has been popular in the literature. The Hansen (1999) threshold analysis works with only exogenous indicators. The model is static and demands the covariates to be strictly exogenous. Due to the difficulties associated with the exogenous assumption, Seo and Shin (2016) broadened the model to the dynamic panel threshold regression (DPTR) model. They allow for the lagged outcome variable and other independent variables to be endogenous. The DPTR model assumes a discontinuity in the regression function, meaning that an abrupt change occurs when the threshold value is reached (Seo *et al.*, 2019). However, this might indicate a smooth change or kink rather than a sudden jump (Cheloufi, 2023). Following the estimation procedure by Hidalgo *et al*. (2019), Seo *et al*. (2019), and Kim (2021), the study utilized the dynamic panel threshold with a kink in public debt to achieve objective two. The model is written as

$$EPI_{it} = \alpha_0 + \propto EPI_{i,t-1} + \emptyset W_{it} + \delta Pd_{it} + \theta(Pd_{it} - \varphi)I(Pd_{it} \geq \varphi) + v_i + \varepsilon_{it} \quad \ldots (18)$$

Where EPI_{it} is the environmental quality, $EPI_{i,t-1}$ capture the dynamic aspect. Pd is the general public debt. φ is the threshold estimate. The change in the slope of public debt at an unknown debt level (φ) is given by θ. $\theta(Pd_{it} - \varphi)I(Pd_{it} \geq \varphi)$ ensures continuity in a change in debt without a jump. Equation (18) is transformed by using the first order difference (GMM) model to obtain Equation (19).

$$\Delta EPI_{i2} = \propto (\Delta EPI_{i3}) + \emptyset(\Delta W_{i2}) + \delta(\Delta Pd_{i2}) + \theta[(Pd_{i2} - \varphi)I(Pd_{i2} \geq \varphi) - (Pd_{i1} - \varphi)I(Pd_{i1} \geq \varphi)] + (\Delta\varepsilon_{i2}) \quad \ldots (19)$$

Where $\Delta EPI_{i2} = EPI_{i2} - EPI_{i1}$, $\Delta Pd_{i2} = Pd_{i2} - Pd_{i1}$, $\Delta\varepsilon_{i2} = \varepsilon_{i2} - \varepsilon_{i1}$, $\Delta W_{i2} = W_{i2} - W_{i1}$, $\Delta EPI_{i3} = EPI_{i3} - EPI_{i2}$. The interest is to estimate δ, which represents the impacts of public debt, θ, which represents the kink slope, also known as the change in the regime of $Pd_{it} < \varphi$ and $Pd_{it} \geq \varphi$ and finally, the unknown threshold value φ.

Post Estimation Diagnostic Tests

To verify the validity and consistency of the GMM estimator, the test has to fulfil two conditions. The Sargan test for over-identification restriction and the

Arellano-Bond test for autocorrelation (AR) Test. These two tests check whether the error terms are serially uncorrelated and whether the instruments are reliable.

Chapter Summary

The methodological processes appropriate for the study were discussed and presented. The section displayed the variables' data type, sources, and justification. The EPI was used to measure environmental quality, serving as the outcome variable. Public debt and external debt are the primary independent variables. The material footprint was used as a mediating variable, and a dummy variable showing a form of green commitment constructed from the ratification of the African Convention on the Conservation of Nature and Natural Resources was used as a moderating variable. The control variables used in the study were discussed. The system GMM estimation technique and the dynamic panel threshold regression model were discussed.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Introduction

This chapter presents and discusses the various results obtained from the study. It discusses descriptive statistics, correlation analysis, linear and non-linear dynamic panel-data analysis, mediation and moderation analysis, and the post-estimation outcomes.

Descriptive Statistics

Table 2 presents the descriptive statistics of the variables used in the study, including the mean, standard deviation, minimum and maximum values, and the number of observations.

Table 2: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Environmental Performance Index	518	42.46	11.306	12.13	74.817
Public Debt	518	41.306	27.566	.488	366.805
External Debt	489	42.219	47.971	4.168	434.518
Urbanisation	518	3.973	1.15	.21	7.596
Foreign Direct Investment	518	4.667	9.106	-17.292	103.337
Renewable Energy Consumption	518	12.012	9.995	.656	52.645
Agriculture	518	21.074	12.527	.893	65.598
Industrialisation	518	27.208	13.124	4.429	84.349
Economic growth	518	3.998	4.799	-36.392	21.452
Forest Area	518	32.817	23.826	.303	91.841
Green Commitment	518	.27	.445	0	1
Material Footprint	518	93701288	1.246e+08	4876111	7.938e+08

Source: Author’s own construct, 2025.

The average EPI value is 42.2. The average value of 42.2 indicates a moderate environmental performance across the region. The largest and lowest EPI values are 74.814 and 12.13, respectively, showing a significant disparity in environmental performance. The standard deviation for EPI is 11.306.

The mean government debt level in the sub-region stood at 41.306 (% of GDP), followed by a standard deviation of 27.566%. This shows a considerable dispersion in government debt across the selected countries, with minimum and maximum standing at 0.488% and 366.805% of GDP, respectively. This significant variation may result from differences in fiscal policies and economic conditions. The average external debt stood at 42.219 (% of GNI), with a high standard deviation of 47.971%. External debt levels range from 4.168% to 434.518%, showing how some economies in the sub-region depend on external borrowing. Regarding urbanisation, the individual observations are about 1.15%, which is a spread from the mean, which stood at 3.973%. Urbanisation levels range from 0.21% to 7.595%, suggesting significant variation in urban growth and infrastructure advancement. The average foreign direct investment stood at 4.667 (% of GDP), while renewable energy consumption recorded a mean value of 2.012. Foreign direct investment ranges from -17.292% to 103.337%, while renewable energy consumption's lowest and highest values stood at 0.656 and 52.645.

Within the selected countries, the mean contribution of agriculture to the economies was 21.074%, with a variation of 12.527%. The added agricultural value (% of GDP) ranges from 0.893% to 65.598%. The industrial sector contributes an average of 27.208% to the economy's GDP and deviates by 13.124%, reflecting variability in industrial development. The maximum value of industrialisation within the region was 84.349%, while the minimum value was 4.429%.

On average, the economic growth rate was recorded at 3.998%, with a variation of 4.799%. The minimum and maximum economic growth rates are -36.392% and 21.452%, respectively. Also, forest area (% of land area) average value stood at 32.817%, with a variation of 23.826%. Forest area values range from 0.303% to 91.841%. The mean green commitment is 0.27 with a variation of 0.445. The variable ranges from 0 to 1.

The results show that the Material footprint measured in metric tons (Mt) has a mean value of 93,701,288 Mt and a standard deviation of 124,600,000 Mt, indicating significant variability in resource consumption across the sample. The minimum and maximum values stood at 4,876,111 Mt and 793,800,000 Mt, respectively.

Environmental Performance Index (EPI) for Countries

Figure 4 shows the mean values of the Environmental Performance Index for ten selected countries within the study periods. Cote D'lvoire, Botswana and Tanzania recorded the highest scores among the selected countries at 58.46, 55.70 and 54.22, respectively. These values are not significantly different from the 2024 EPI scores, where Botswana recorded a score of 49.2 and ranked 66th globally. Tanzania and Cote D'lvoire scored 43.6 and 42.9 and ranked 102 and 104 respectively. Benin, South Africa, Ghana and Kenya recorded moderate scores; their mean values were 48.16, 45.15, 45.11 and 41.73. The countries that registered the lowest scores among the ten selected countries are Cameroon (29.25), Angola

(36.15) and Burkina Faso (38.86). Overall, these statistics indicate different variations in environmental performance among the countries.

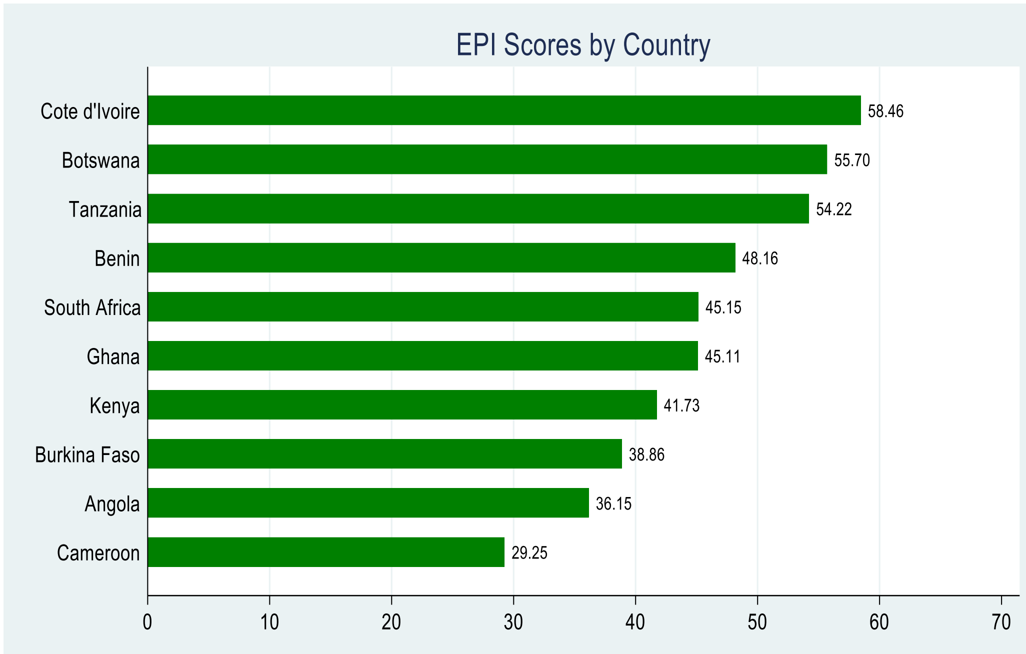

Figure 5: Environmental Performance Index by countries

Source: Data from YCELP (2022)

Environmental Performance Index in Terms of Income Groupings

Figure 5 presents Sub-Saharan Africa's average environmental performance by income level. The bar chart portrays a positive nexus between income levels and the environmental performance index. The EPI score for Low-income countries stood at 39.26. This may suggest that Low-income countries have limited resources to ensure environmental improvement. Furthermore, these countries may have loose environmental laws that attract foreign companies into the environmentally destructive sectors, including mining and construction. Low-middle-income countries show a slight advancement with a moderate score of 41.94. Upper-middle-income countries recorded the highest mean EPI value of

55.06. This suggests that environmental management and eco-friendly investment are prioritised as countries prosper. This trend conforms to the EKC hypothesis, which stipulates that ecosystem outcomes improve as countries get wealthier.

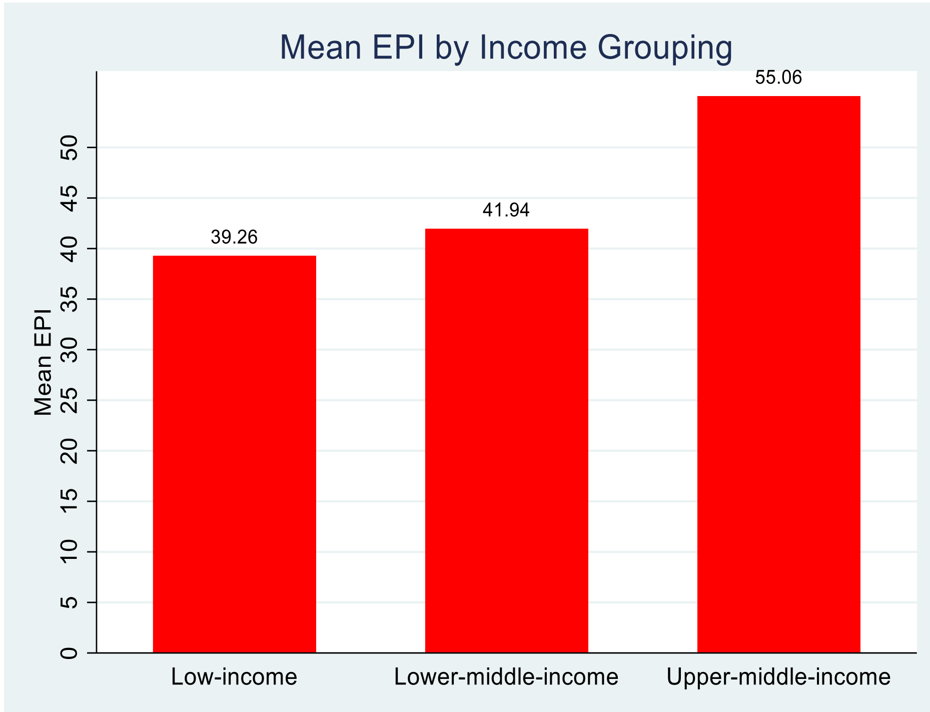

Figure 6: Environmental Performance Index in terms of income level

Source: Data from YCELP (2022)

Environmental Performance Index in Terms of Regional Groupings

Figure 6 presents the EPI scores across various regional groupings in SSA. It is seen that the Southern African countries have the highest environmental performance index score with a mean value of 46.08. This is followed by the Central African Countries, with an average value of 43.09. The mean EPI value for the East African state stood at 41.22, while the West African State recorded the lowest mean value of 41.00, slightly below the EPI mean value for the East African Countries.

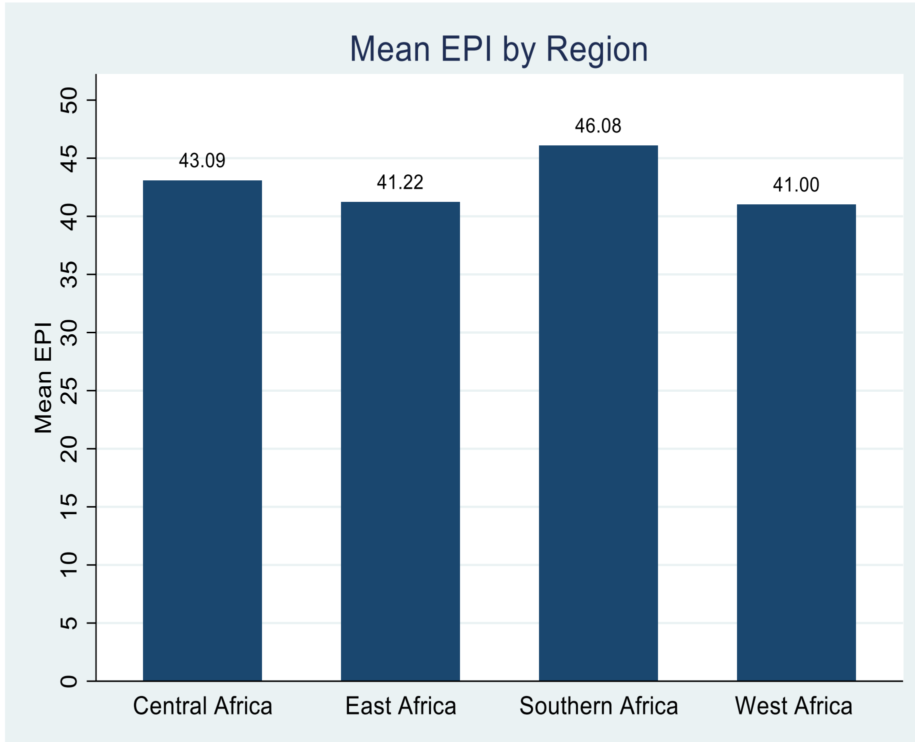

Figure 7: Environmental Performance Index in terms of regional groupings

Source: Data from YCELP (2022)

Correlation Analysis

Table 3 presents the correlation between the variables used in the study. This analysis helps determine the presence of multicollinearity among the variables. All the independent variables are significantly correlated with the environmental performance index except for renewable energy consumption, external debt, urbanization and growth in gross domestic product. Public debt reveals a weak but statistically negative correlation with the environmental performance index (-0.087), suggesting that increased public debt levels are associated with lower environmental conditions. Furthermore, the result reveals that although external borrowing is insignificant, it is negatively correlated to EPI (-0.001). Green commitment is negatively correlated to EPI with a correlation coefficient of (-0.120). The material footprint is also inversely associated with EPI. This shows that higher resource consumption leads to more environmental deterioration. The correlation outcomes portray a non-existing multicollinearity among the variables.

Table 3: Pairwise Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) EPI	1.000											
(2) PD	-0.087*	1.000										
(3) ExD	-0.001	0.647*	1.000									
(4) Urbg	0.044	-0.022	-0.001	1.000								
(5) FDI	-0.138*	0.057	0.191*	0.049	1.000							
(6) REC	-0.076	0.101*	0.105*	0.301*	0.176*	1.000						
(7) Agric	-0.389*	0.167*	0.036	0.206*	0.195*	-0.115*	1.000					
(8) Indus	0.258*	-0.140*	-0.031	0.092*	-0.063	0.627*	-0.683*	1.000				
(9) GDPG	-0.064	-0.173*	-0.143*	0.183*	0.092*	0.017	0.167*	-0.104*	1.000			
(10) Forest	0.211*	0.112*	0.192*	0.014	0.265*	0.490*	-0.259*	0.509*	-0.081	1.000		
(11) Rat	-0.120*	0.024	-0.038	-0.091*	-0.051	-0.107*	0.117*	-0.206*	-0.034	-0.246*	1.000	
(12) MF	-0.090*	-0.103*	-0.104*	0.089*	-0.135	-0.091*	-0.026	-0.063	0.068	-0.160*	0.020	1.000

*** shows the level of significance at 5% level**
Source: Author's own construct, 2025**.**

Linear Effect of Public Debt on Environmental Quality in SSA.

Table 4 shows the linear effect of public debt on environmental quality performance in SSA.

Table 4: Linear effect of public debt on environmental quality in SSA

Variable	**EPI** **Model 1**
L.EPI	0.926***
	(0.056)
PD	**-0.015****
	(0.006)
URBG	-0.044
	(0.271)
FDI	-0.018
	(0.012)
REC	0.024
	(0.034)
Agric	-3.101***
	(0.703)
Indus	-0.102***
	(0.037)
GDPG	0.103***
	(0.018)
Forest	-0.086**
	(0.039)
Constant	17.624***
	(4.431)
Number of inst	**33**
Number of Groups	**37**
Sargan test	**0.1714**
AR 1	**0.0002**
AR 2	**0.3365**
N	**481**

Standard errors in parentheses $p < 0.1$*, $p < 0.05$**, $p < 0.01$***

Source: Authors own construct, 2025**.**

The coefficient of public debt is -0.015. This is statistically significant at 5%. This indicates that a one per cent increase in government borrowing (% of GDP) generates a 0.015-point decline in environmental quality in the sub-region. The results depict a negative nexus of government borrowing and the environmental performance index. The result confirms the debt overhang effect, that as countries grappling with increasing debt challenges will likely disregard investment in environmental sustainability.

Challenges associated with accessing the financial markets, often sparked by debt restructuring and defaults, increasingly lead some resource-dependent African states to rely on resource-backed loans (Coulibaly, 2024). This financial model worsens environmental performance as governments acquire loans by promising future natural resource revenues as collateral, uniquely affecting SSA. This is so as debt-distressed countries feel pressured to extract more resources to meet loan obligations. Such arrangements raise environmental concerns due to potential mining in reserve parks and protected ecological areas. Countries including Ghana, Angola, Guinea and DR Congo are among the nations in the sub-region that have mortgaged future revenue natural resource exports as collateral.

Furthermore, countries engulfed with high indebtedness often face the need for fiscal consolidation (Miningou, 2023). This highlights the urgent need to restructure the government budget by cutting off some allocations of items that are less rigid and less appealing to voters. Environmental protection often portrays both features, and governments may not have the adequate fiscal ability to absorb climate-induced expenditure and green investment projects (Carnazza *et al*., 2023).

Thus, this will have negative implications for environmental improvement. This finding conforms to Farooq *et al*. 2023 who found public debt to erode the environmental standards of the Organization of Islamic Countries. Carnazza, Renstrom and Spataro (2023) found that when strict fiscal framework is present, public debt intensifies environmental destruction in EU countries.

Public Debt Threshold for Environmental Quality in SSA

The DPTR result, as outlined in equations (18) and (19) is presented in Table 5. In this analysis, the interest is in providing an interpretation of the estimated values of δ, which represents the effect of public debt before the unknown threshold value φ and θ, which represents the effect of public debt after the unknown threshold value.

Table 5: Non-linear relationship between public debt and environmental quality.

Variable	Model 2
L.EPI	0.482***
	(0.0667)
GDPG	-0.163***
	(0.023)
Forest	1.120**
	(0.550)
Urbg	-4.640***
	(0.398)
FDI	-0.059***
	(0.011)
Agric	-5.210**
	(2.211)
Indus	-0.092
	(0.113)
REC	0.335
	(0.048)
PD(δ)	**0.102****
	(0.044)
Kink_slope(θ)	**-0.198*****
	(0.054)
Threshold Value(φ)	**51.5*****
	(3.472)
Bootstrap p-value for linearity test	**0.000*****

Standard errors in parentheses $p < 0.1$*, $p < 0.05$**, $p < 0.01$***
Source: Author's own construct, 2025.

Results from Table 5 show that the unknown threshold(φ) was 51.5%, statistically significant at 1%. This indicates that the tipping point at which the relationship between public debt and environmental quality changes occurs when government debt reaches approximately 51.5% of GDP. Below this tipping point, government borrowing positively affects environmental quality; however, beyond this threshold value, it becomes harmful.

The estimated threshold value of 51.5% of GDP is consistent with the threshold value of 57.47% of GDP obtained by Andoh *et al.* (2023) on the debt-inequality relationship and the threshold value of 56% of GDP by Yousaf and Aziz (2024) on the public debt-economic growth nexus in selected indebted nations. The coefficient of public debt (δ) below the threshold value is 0.102, and significant at the 5% alpha level. The positive coefficient stipulates that government debt is not harmful to the environment when general government borrowing is below the threshold value of 51.5% in the subregion, as estimated by (φ). This finding implies that lower government debt potentially aids governments in servicing their debt without putting pressure on the environment. The government can divert resources to address ecosystem difficulties (Boly *et al*., 2019; Alhassan & Kwakwa,2022).

However, as public debt exceeds this threshold value, its effect on the ecosystem becomes negative. The estimated slope of public debt(θ) above the threshold value is -0.198 and is statistically significant at the 1% level. The negative slope indicates a decline in environmental performance when government borrowing surpasses the threshold value. This suggests that as debt accumulation rises, eco-friendly investments become unattractive, and governments prioritise debt servicing over ecosystem protection (Alhassan & Kwakwa,2022). The threshold analysis findings depict a U-shaped nexus between government borrowing and environmental quality in SSA. A bootstrap P-value of (0.00) indicates the presence of a threshold effect. This study supports the findings of Clootens (2017), Alhassan and Kwakwa (2022), and Li *et al*. (2022), who revealed a U-shaped nexus between debt and environmental outcomes.

Natural Resource Extraction as a Mediator between Debt and Environmental Quality.

The role of resource extraction as a mediator in the interplay between debt and the environment is presented in Table 6. To assess the existence of the mediation effect of resource extraction, the study employed the mediation effect model outlined in Equations (14), (15), and (16).

Table 6: The Role of Natural Resource Extraction as a Mediator in the Debt-Environment Relationship.

Variables	EPI Model 3	Lmf Model 4	EPI Model 5
L.EPI	0.955***		0.928***
	(0.050)		(0.067)
EXD	**-0.0134*** **	**0.00208** **	**-0.00687**
	(0.050)	**(0.0009)**	**(0.004)**
lmf			**-1.5022*** **
			(0.211)
FDI	0.040***	-0.000161	-0.0316***
	(0.013)	(0.0005)	(0.012)
REC	-0.007	-0.00172	-0.033024**
	(0.016)	(0.0009)	(0.015)
Urbg	-0.199	-0.0298***	0.04006
	(0.265)	(0.0078)	(0.279)
Agric	-0.134***	0.00527***	-0.14259**
	(0.036)	(0.0007)	(0.059)
GDPG	0.101**	0.00589***	0.12042***
	(0.018)	(0.0011)	(0.024)

Forest	-0.077**	0.000921	-0.07819**
	(0.037)	(0.0007)	(0.040)
L.lmf		0.933***	
		(0.0008)	
cons	8.979***	1.171***	36.00***
	(3.124)	(0.018)	(6.315)
N		**455**	

Standard errors in parentheses $p < 0.1^{*}$ $p < 0.05^{**}$, $p < 0.01^{***}$

Source: Author's own construct, 2025**.**

Model (3) in Table 6 shows that the estimated coefficient of external debt (-0.0134) has a negative association with the Environmental Performance Index, statistically significant at the 1% level. This implies that a 1% increase in external debt (as a percentage of GNI) results in a 0.0134-point decline in environmental quality in SSA, ceteris paribus. This finding is consistent with Bese *et al.* (2021) and Carrera and Vega (2024) but contrasts with Ezenekwe et al. (2023), who found that external borrowing enhances environmental performance. The inverse relationship between external borrowing and environmental performance may imply that higher external borrowing might weaken the government's ability to enforce strict environmental regulations, potentially due to foreign pressure (Carrera & Vega, 2022). In addition, external borrowings, such as Chinese loans targeted at high-energy consumption sectors, including the mining industry, construction, and infrastructure sectors, can have adverse environmental implications (Jianhua, 2022; Bese *et al.*, 2021; Sun & Liu, 2020).

Model (4) indicates that external debt positively affects resource extraction. The coefficient of external debt (0.00208) is significant at a 5% level. The results indicate that a 1% increase in external debt is associated with a 0.208% rise in resource extraction in the sub-region, ceteris paribus. This trend is particularly evident in Sub-Saharan Africa, where many countries depend heavily on resource revenues from exports. This finding supports the debt-resource hypothesis, which posits that nations with higher debt burdens are more likely to exploit their natural resources to generate the necessary revenue and foreign exchange to fulfil their debt obligations (Neumayer, 2005)

In model (5), the coefficient of material footprint (-1.502) is statistically significant and negatively related to EPI. This demonstrates that a one per cent increase in resource extraction reduces environmental performance by 1.502 points. Furthermore, the estimated coefficient of external debt (-0.0068) has an inverse relationship with environmental quality, but it is statistically insignificant. The mediation analysis results revealed that external debt degrades the environment by promoting the usage of natural resources, and the material footprint is a complete mediation variable.

The Relationship between Public Debt and Environmental Quality when Green Commitment exists.

Table 7 shows how government's commitment to regional green agreements can influence the effect of public debt on environmental quality.

Table 7: The moderating role of green commitment in the public debt-environment relationship.

Variable	EPI Model 6
L.EPI	0.851*** (0.054)
PD	**-0.361*** (0.011)**
Rat	**6.228*** (1.391)**
Rat_PD	**0.200** (0.009)**
REC	-0.074** (0.035)
Agric	-6.015*** (0.989)
Indus	-0.042 (0.046)
GDPG	-0.045** (0.023)
Forest	0.081** (0.032)
URBG	0.359 (0.361)
FDI	-0.050*** (0.015)
Constant	24.953*** (4.704)
Number of inst	**35**
Number of Groups	**37**
Sargan test	**0.208**
AR1	**0.0003**
AR2	**0.4083**
N	**481**

Standard errors in parentheses $p < 0.1$*, $p < 0.05$**$p < 0.01$***

Source: Author's own construct, 2025**.**

Table 7 shows that government ratification of the African Convention on the Conservation of Nature and Natural Resources, which portrays a form of government commitment to protect the environment, has a positive link with environmental quality. The estimated coefficient of green commitment (Rat) is 6.229 and significant at 1%. This shows that countries that are committed to green agreements have 6.229 points of improvement in environmental quality than countries that do not have green commitments. This suggests that countries enjoy improved environmental standards when governments commit to and align with stringent environmental agreements. This finding supports the notion that international agreements and commitments are essential in driving ecosystem conservation, particularly in countries with weak internal regulatory frameworks for environmental protection. This revelation aligns with Kim *et al.* (2017), who found a legally binding international environmental agreement to improve environmental standards.

Furthermore, the study interacted public debt and green commitment (Rat_PD) to achieve objective 4. This helps examine how green commitment influences the interplay between government debt and environmental quality in SSA. The coefficient of the Rat_PD (0.200) interaction variable is positive and significantly influences environmental quality. This demonstrates that green commitment through the ratification of regional environmental agreements plays an essential transmitting role in the public debt - environmental quality nexus. To obtain the net effect of green commitments, equation (17) was transformed to get;

$$\frac{\Delta EPI_{i,t}}{\Delta PD_{i,t}} = \alpha_1 + \alpha_3 Rat_{i,t}$$

$$\frac{\Delta EPI_{i,t}}{\Delta PD_{i,t}} = -0.361 + 0.200(Rat_{i,t})$$

Placing the average value of the Green Commitment, which is (0.27) from the table 2, gives;

$$\frac{\Delta EPI_{i,t}}{\Delta PD_{i,t}} = -0.361 + 0.200(0.27)$$

$$\frac{\Delta EPI_{i,t}}{\Delta PD_{i,t}} = -0.361 + 0.200(0.27)$$

$$\frac{\Delta EPI_{i,t}}{\Delta PD_{i,t}} = -0.361 + 0.054$$

$$\frac{\Delta EPI_{i,t}}{\Delta PD_{i,t}} = -0.307$$

Although green commitment positively influences the transmission of public debt's effect on environmental quality, the negative direct effect surpasses the positive interaction effect, leading to an overall negative net effect in this analysis. The net effect depicts that when green commitment exists, the negative effect of public debt on environmental quality is reduced to -0.307. This demonstrates that while public debt alone can stress resource extraction, which leads to environmental destruction, green commitment through regional green agreements can mitigate some of this effect. The moderation effect is modest and shows that most governments prioritise economic goals and debt repayment efforts over environmental protection. Also, weak governance and corruption can hinder the implementation of green commitments, allowing harmful practices to continue despite political intentions.

Effects of Other Variables on Environmental Quality in Sub-Saharan Africa.

The lag value of the EPI is statistically significant at the 1% level, showing that the previous year's environmental quality influences the current year's environmental performance at an average of 0.851. The findings from Table 7 suggest that FDI degrades environmental quality in SSA. As FDI increases by one per cent, the environmental qualty in SSA reduce by 0.050 points. This finding supports the work of Bokpin (2017), Opoku and Boachie (2020), and Boamah *et al.* (2023). This revelation may be attributed to ineffective environmental policies in most countries in the region, supporting the pollution haven arguments, which stress that capital will flow into poor nations with lax environmental standards.

Renewable energy consumption (REC) also negatively influences environmental quality, reducing environmental performance by approximately 0.074 points. The negative and significant relationship between renewable energy consumption and environmental quality indicates a counterintuitive relationship, where higher renewable energy consumption is linked to reduced environmental performance. Asongu e*t al.* (2019) demonstrated that while renewable energy consumption generally leads to a reduction in $C0_2$ emissions, the extent of this varies across different levels of emissions and types of renewable energy sources. Their study suggests that in regions where traditional biomass constitutes a significant portion of renewable energy consumption, the anticipated environmental benefits may not fully materialise due to associated deforestation and indoor air pollution. This finding contradicts Salem *et al.* (2021) and Mukhtarov *et al.* (2022).

Regarding agriculture (Agric), the study found an inverse relationship between agriculture and environmental performance in SSA, which is statistically significant at the 1% level. This implies that a rise in agricultural activities leads to an average decline of 6.015 points in environmental quality. This outcome aligns with prior expectations and supports the works of Bekun and Agboola (2019) and Adedoyin *et al*. (2021).

The study further shows that the selected economies' annual GDP growth rates affect their ecosystem outcomes. This study reveals that economic advancement detrimentally affects the environment and is statistically significant at the 5% alpha level. This finding might be ascribed to the environmental stresses accompanying economic growth, such as increased infrastructure development, energy use, waste management, and resource extraction. This reveals that a one per cent increase in economic growth leads to a 0.045-point reduction in environmental quality. This outcome aligns with the work of Hess (2016) however, it opposes the findings of Das Neves Almeida *et al.* (2017).

The forest area (Forest) coefficient implies that high-quality forest areas are associated with higher environmental performance. The coefficient of the relationship between forest area and environmental performance is 0.081 and is statistically significant at the 5% level. This indicates that ceteris paribus, a 1% increase in forest area is associated with an approximate 0.081-point improvement in environmental quality. This finding conforms to the study by Raihan (2023), who found that a 1% increase in forest area leads to a 3.6% decline in CO_2 emissions.

Post Estimation Results

Table 4 and Table 7 present the results on the effect of public debt on environmental quality and the moderating role of green commitment. The Sargan test p-values of (0.171) in model 1 and (0.208) in model 6 show that the instruments are valid. Furthermore, the significant AR (1) p-values of (0.0002) and (0.0003) and insignificant AR (2) p-values of (0.3365) and (0.4083) in models 1 and 6 indicate the models do not suffer from first and second-order autocorrelation.

Chapter Summary

The chapter discussed the regression results obtained to address the objectives of this study. It also discussed descriptive statistics, correlation analysis, mediation and moderation analysis, non-linear and linear dynamic panel analysis, and post-estimation outcomes. The study found that when government debt increases by one per cent, the quality of the environment in SSA will degrade by 0.015 points.

In addition, the dynamic panel threshold estimation reveals a public debt threshold value of 51.5%. The threshold analysis findings depict a U-shaped nexus of government borrowing and environmental performance in SSA and show that below a value of 51.5%, public debt does not harm the environment. However, beyond that, it is detrimental to the environment. These implications are crucial for policymakers and researchers interested in environmental economics and public policy.

The study further analysed the pathway through which external debt can influence environmental quality and found that resource extraction, measured by material footprint, is a complete mediator. This highlights the subregion's reliance on natural resource extraction, mainly resource revenue from exports, and its essential role in debt servicing. This study supports the debt–resource hypothesis.

Finally, the study found that green commitments moderate the link between public debt and environmental quality.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter provides the summary, conclusions, and recommendations for the study. The summary section offers an overview of the previous chapters. The chapter also outlines recommendations to relevant authorities and concludes with proposals for future research.

Summary

Numerous research has been undertaken to explain how government debt affects macroeconomic indicators, including economic growth and investment, and social factors, such as inequality. Research on the link between government borrowing and environmental outcomes has yielded conflicting results. While some studies revealed a direct relationship, others found an inverse or insignificant relationship. This highlights the need for further studies, especially in SSA, where the effect of increasing government borrowing and environmental challenges heavily impacts communities.

This research addresses the following research question: Does increasing government debt exert pressure on the environment in SSA? In addition, the study examined the moderating role of green commitment and the mediating role of resource extraction in the debt–environment nexus and paid attention to the possible non-linear relationship. The System GMM model and the dynamic threshold model were employed to achieve the objectives of the study. This study uses panel data spanning 14 years and 37 countries from SSA.

The study found that debt exerts pressure on the environment, and resource extraction mediates this relationship in the region. This confirms the debt overhang theory and debt resource hypothesis. The study highlighted that below the tipping point of 51.5%, public debt does not degrade the environment; however, beyond 51.5%, public debt is detrimental to the environment. The threshold analysis findings depict a U-shaped relationship. The study demonstrated that green commitment positively affects the environment and is essential in diluting the adverse effect of debt on the environment. However, the impact of the net effect was found to be modest. The outcome of the control variables shows that foreign direct investment, renewable energy consumption, agriculture, and economic growth negatively impact environmental improvement. At the same time, forest areas significantly enrich the environmental performance of SSA.

Conclusions

The study concluded that the relationship between public debt and the environmental performance index is not linear. This implies that public debt is not entirely harmful to the environment. It demonstrates that when government debt is below the threshold value of 51.5%, governments can service their debt without putting pressure on the environment. However, above the threshold value of 51.5% of debt to GDP, government borrowing becomes detrimental to the environment.

The study concluded that there is a U-shaped nexus between government debt and environmental performance in SSA

In addition, the study reveals that the detrimental effect of external debt on the environment is transmitted through resource extraction. This shows that in the subregion, debt induces reliance on natural resources. This reliance can be attributed to an increase in the extraction of natural resources to generate foreign exchange to service government external borrowing.

Furthermore, green commitment is essential and positively affects environmental performance in the sub-region. This shows that countries that have ratified some regional environmental standards, specifically, the African Convention on the Conservation of Nature and Natural Resources, witnessed a reduction in the detrimental effect of public debt on the environment.

Recommendations

The following recommendations are derived from the study’s findings.

Finance ministries in SSA countries should manage public debt carefully to avoid exceeding the threshold value of 51.5 (% of GDP), at which point debt begins to harm the environment. Management strategies should include initiatives that prioritise sustainable borrowing and debt servicing.

Environmental regulatory authorities in Sub-Saharan Africa should integrate sustainable natural resource management into national policies to decouple high indebtedness from resource extraction. This approach can foster economic advancement and enhance welfare while simultaneously reducing resource usage and ecological impacts.

Government within the sub-region should strengthen their green commitment by actively participating in and enforcing international and regional green agreements, such as the African Convention on the Conservation of Nature and Natural Resources that enhance the ecosystem and promote sustainable resource management. Joining this international environmental treatise enables member countries to align with regional and global environmental standards for environmental protection, enhance their policy frameworks, and strengthen enforcement mechanisms. Such agreements also provide collaboration, funding, and knowledge-sharing opportunities to support member countries' environmental goals.

Areas for Further Studies

The study focused on examining the nexus of government debt and environmental quality, the role of green commitment in SSA, and the pathway through which debt can affect environmental quality. Further studies could also incorporate fiscal consolidation by using the IMF fiscal rule and examine the association of government debt on environmental performance in the presence of fiscal rule in the sub-region.

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APPENDICES

List of Countries that have Signed and Ratified the Conversion

Countries	Signature	Ratification
Angola	Signed	Ratified
Benin	Signed	Ratified
Botswana	Not Signed	Not Ratified
Burkina Faso	Signed	Ratified
Burundi	Signed	Ratified
Cameroon	Not Signed	Not Ratified
Central Africa Republic	Signed	Not Ratified
Chad	Signed	Ratified
Congo, Dem. Rep	Signed	Not Ratified
Congo, Rep	Signed	Ratified
Cote d'Ivoire	Signed	Ratified
Equatorial Guinea	Signed	Not Ratified
Eswatini	Not signed	Not Ratified
Ethiopia	Signed	Not Ratified
Gabon	Signed	Ratified
The Gambia	Signed	Ratified
Ghana	Signed	Ratified
Guinea	Signed	Not Ratified
Kenya	Signed	Not Ratified
Liberia	Signed	Ratified
Madagascar	Signed	Not Ratified
Malawi	Not Signed	Not Ratified
Mali	Signed	Ratified

Mauritania	Signed	Not Ratified
Mozambique	Signed	Not Ratified
Namibia	Signed	Not Ratified
Niger	Signed	Ratified
Nigeria	Signed	Not Ratified
Rwanda	Signed	Ratified
Senegal	Signed	Not Ratified
Sierra Leone	Signed	Not Ratified
South Africa	Signed	Ratified
Tanzania	Signed	Not Ratified
Togo	Signed	Not Ratified
Uganda	Signed	Not Ratified
Zambia	Signed	Not Ratified
Zimbabwe	Signed	Not Ratified

Indicators of Environmental Performance Index

Indicator	Description
Biodiversity Habitat Index **BHV**	The consequences of habitat loss, deterioration, and fragmentation on the anticipated persistence of terrestrial biodiversity are estimated by the Biodiversity Habitat Index (BHI).
Black Carbon Growth Rate **BCA**	The average yearly rate of rise or fall in black carbon from 2010 to 2019 and then corrected for economic trends.
CH_4 Growth Rate **(CHA)**	It is the average yearly rate of rise or decrease in raw methane emissions from 2010 to 2019. Economic trends are considered to separate change brought on by policy from economic volatility.
CO Exposure **(COE)**	It is measured as the population-weighted annual average concentration of CO at ground level.
CO_2 from land cover **(LCB)**	Tracks the CO_2 emissions growth or decline brought on by changes in land use calculated as the average yearly growth rates in emission over ten-year period.
CO_2 growth rate **(CDA)**	It is estimated as the average yearly rate of growth or contraction in the emissions of raw carbon dioxide during a ten-year period.
Controlled Solid Waste **MSW**	The percentage of domestic and commercial garbage created in a nation that is gathered and handled in a way that reduces environmental concerns
F-Gas Growth Rate **FGA**	The average yearly rate of increase or decrease in raw fluorinated gas emissions from 2010 to 2019 is used to compute the F-gas growth rate.
Fish Caught by Trawling **FTD**	The proportion of a nation's fish caught by bottom trawling, which involves pulling a fishing net down the seafloor behind a boat, or dredging, which involves scraping the seafloor in search of species that live at the bottom
Fish Stock Status	Fish stock status measures the proportion of a nation's overall catch that comes from overfished or depleted

FSS	stocks while considering all fish stocks found within a nation's EEZs
GHG Emissions per Capita **GHP**	it determines the overall amount of greenhouse gas emissions and then divided by population
GHG Intensity Trend **GIB**	It is the yearly average growth rate in GHG emissions per unit of GDP.
Grassland Loss **GRL**	A five-year moving average of the percentage of gross losses in grassland areas relative to the 1992 reference year
Household Solid Fuels **HAD**	The number of age-standardized disability-adjusted life years lost per 100,000 people (DALY rate) as a result of exposure to household air pollution (HAP) from the use of domestic solid fuels
Lead Exposure **PBD**	the ratio of age-standardized disability-adjusted life years (DALY rate) lost per 100,000 people due to exposure to lead contamination in the environment
Marine Protected Areas **MPA**	The percentage of a nation's total exclusive economic zone (EEZ) that is designated as marine protected areas
Marine Trophic Index **RMS**	it is the predicted catches and changes over time in the fishing stock of the nation.
N_2O Growth Rate **NDA**	The average yearly rate of increase or reduction over the period 2010–2019 and then corrects for economic trends.
NOx Exposure **NOE**	The population-weighted annual average concentrations of NO_x
NO_x Growth Rate **NXA**	The average yearly rate of NOX growth or decline for the period of 2010 to 2019. Economic volatility is catered for.
Ocean Plastic Pollution **OCP**	The total mass of post-consumer plastics entering the ocean every year was used to calculate the amount of plastic pollution in the ocean.

Ozone Exposure (OZD)	It is measured by the number of age-standardized, disability-adjusted life years lost per 100,000 people (DALY rate) because of exposure to ground-level ozone pollution.
$PM_{2.5}$ Exposure PMD	It is measure by the ratio of age-standardized disability-adjusted life-years lost per 100,000 people (DALY rate) as a result of exposure to fine air particulate matter smaller than 2.5 micrometres (PM2.5).
Projected GHG Emissions in 2050 (GHN)	It is calculated by extrapolating the trend in emissions over the past ten years and calculating the average rate of increase or decline.
Protected Areas Rep. Index PAR	The amount of biologically scaled environmental variety present in a nation's terrestrial protected areas
Recycling Rate (REC)	It is calculated as the percentage of post-consumer recyclable materials (glass, plastic, paper, and metal) that are recycled.
SO_2 Exposure SOE	the population-weighted annual average concentrations of SO_2
SO_2 Growth Rate SDA	SO2's average yearly rate of growth or decline from 2010 to 2019. Economic trends are considered to separate change brought on by policy from economic volatility.
Species Habitat Index SHI	The SHI indicator calculates the percentage of each species' necessary habitat that is still present in a nation in comparison to a base line established in 2001.
Species Protection Index SPI	The SPI metric uses remote sensing data, global biodiversity informatics, and integrative models to create high-resolution habitat maps for over 30,000 terrestrial vertebrates, invertebrates, and plant species.
Sustainable Nitrogen Mgmt. Index (SNM)	Correlation between effective nitrogen fertilizer application and maximum crop yields.
Sustainable Pesticide Use	The indicator is created by modifying a country's pesticide risk score using pesticide application rates

SPU	
Terrestrial Biome Protection (global) **TBG**	Protection percentages are weighted for the terrestrial biome protection (global weights) indicator based on how common each type of biome is throughout the world.
Terrestrial Biome Protection (national) **TBN**	this indicator measures how well a nation is doing at protecting all biomes to a 17 percent level inside its borders. Protection percentages are weighted by the frequency of each biome type in that nation
Tree Cover Loss **TCL**	The proportion of forest that has been lost relative to the level of forest cover in the reference year 2000 was calculated into a five-year moving average
Unsafe Drinking Water **UWD**	the ratio of age-standardized disability-adjusted life years (DALY rate) lost per 100,000 people due to exposure to unsafe drinking water
Unsafe Sanitation **USD**	the ratio of age-standardized disability-adjusted life years (DALY rate) lost per 100,000 people due to exposure to subpar sanitation facilities
VOC Exposure **VOE**	the population-weighted annual average concentrations of VOC
Wastewater treatment **(WWT)**	The indicator is measured as the percentage of wastewater that receives at least primary treatment in each nation, normalized by the share of the population that is connected to a municipal wastewater collection system
Wetland Loss **WTL**	The consequences of habitat loss, deterioration, and fragmentation on the anticipated persistence of terrestrial biodiversity are estimated by the Biodiversity Habitat Index (BHI).

Multicollinearity Test (VIF) for Table 4

Variable	VIF	1/VIF
Indus	5.080	0.197
Agric	2.920	0.341
REC	2.760	0.362
Forest	1.720	0.582
Urbg	1.270	0.786
FDI	1.220	0.819
PD	1.180	0.846
GDPG	1.110	0.897
Rat	1.100	0.910
MF	1.070	0.937
Mean VIF	1.940	

Post Estimation Diagnostic Test of Table 6

	MODEL 3	MODEL 4	MODEL 5
Sargan Test	0.251	0.2631	0.2344
AR 1	0.0004	0.0005	0.0001
AR 2	0.3648	0.0589	0.3724