

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

**ANALYSES ON ENVIRONMENT AND ECONOMIC DEVELOPMENT
IN AFRICA**



Ph.D. THESIS

Derese Kebede TEKLIE

Department of Economics

Economics Programme

MARCH 2025

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

**ANALYSES ON ENVIRONMENT AND ECONOMIC DEVELOPMENT
IN AFRICA**

Ph.D. THESIS

**Derese Kebede TEKLIE
(412182006)**

Department of Economics

Economics Programme

Thesis Advisor: Assoc. Prof. Dr. Mete Han YAĞMUR

MARCH 2025

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

AFRİKA'DA ÇEVRE VE İKTİSADİ GELİŞME ÜZERİNE ANALİZLER

DOKTORA TEZİ

**Derese Kebede TEKLİE
(412182006)**

İktisat Anabilim Dalı

İktisat Programı

Tez Danışmanı: Doç. Dr. Mete Han YAĞMUR

MART 2025

Derese Kebede TEKLIE, a Ph.D. student of İTÜ Graduate School student ID 412182006 successfully defended the dissertation entitled “ANALYSES ON ENVIRONMENT AND ECONOMIC DEVELOPMENT IN AFRICA”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor: **Assoc. Prof. Dr. Mete Han YAĞMUR**
İstanbul Technical University

Jury Members : **Assist. Prof. Dr. Shourjo CHAKRAVORTY**
İstanbul Technical University

Assist. Prof. Dr. Mahmut Sami GÜNGÖR
Marmara University

Assoc. Prof. Dr. Aysun HIZIROĞLU AYGÜN
İstanbul Technical University

Assoc. Prof. Dr. Yunus ÖZCAN
İstanbul Commerce University

Date of Submission : 10 January 2025
Date of Defense : 19 March 2025





To my family,



FOREWORD

The completion of this PhD represents the culmination of an incredible journey filled with learning, perseverance, and personal growth. It is with immense gratitude that I present this work, which would not have been possible without the support, encouragement, and contributions of many remarkable individuals and organizations.

First and foremost, I extend my deepest thanks to my esteemed supervisor, Assoc. Prof. Dr. Mete Han YAĞMUR. His expert guidance, insightful feedback, and steadfast belief in my abilities have been instrumental in shaping the course of this research. His mentorship has been a source of inspiration throughout this journey.

I am also deeply grateful to Assist. Prof. Dr. Shourjo CHAKRAVORTY, Assist. Prof. Dr. Sinan ERTEMEL, Assist. Prof. Dr. Mahmut Sami GÜNGÖR, and Prof. Dr. Bülent GÜLOĞLU. Their invaluable insights, thoughtful advice, and unwavering support have greatly enriched my research and contributed to its success. Their expertise and encouragement were key to navigating this academic journey.

I am profoundly grateful to the Türkiye Bursları Scholarship program and the people of Türkiye. Their generosity and commitment to supporting international education provided me with the opportunity to pursue this academic endeavor. Their encouragement and hospitality have played a significant role in my success, and I carry their kindness with me always.

To my family, I owe my deepest gratitude. Your unwavering support, sacrifices, and belief in my potential have been the foundation of my strength and determination. This achievement would not have been possible without your love and encouragement.

I also wish to express heartfelt thanks to my friend, Assist. Prof. Dr. Burak DOĞAN, for his steadfast friendship and support. Your encouragement, understanding, and camaraderie have been invaluable throughout this journey, making the challenges more manageable and the successes more meaningful.

This dissertation is dedicated to all those who have contributed to its realization. Your support and belief in me have made this achievement possible, and I am eternally grateful.

January 2025

Derese Kebede TEKLIE
(Researcher)



TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	ix
TABLE OF CONTENTS	xi
ABBREVIATIONS	xiii
SYMBOLS	xv
LIST OF TABLES	xvii
LIST OF FIGURES	xix
SUMMARY	xxi
ÖZET	xxiii
1. INTRODUCTION	1
2. EFFECT OF ECONOMIC GROWTH ON CO₂ EMISSION IN AFRICA: DO FINANCIAL DEVELOPMENT AND GLOBALIZATION MATTER?	7
2.1 Introduction	7
2.2 Literature Review	11
2.2.1 Economic growth and carbon emission	11
2.2.2 Financial development and carbon emission	13
2.2.3 Globalization and carbon emission	15
2.2.4 Comment and research gap	17
2.3 Methodology	18
2.3.1 Model	18
2.3.2 Data	19
2.3.3 Estimation technique	20
2.4 Empirical Result and Interpretation	23
2.4.1 Descriptive statistics	23
2.4.2 Correlation matrix	24
2.4.3 Effects of globalization on carbon emission in Africa.....	26
2.4.4 Effects of financial development on carbon emission in Africa	33
2.4.5 The moderating effect of globalization and financial development on carbon emission in Africa.....	35
2.5 Conclusion and Recommendation.....	39
3. THE ROLE OF GREEN INNOVATION, RENEWABLE ENERGY, AND INSTITUTIONAL QUALITY IN ACHIEVING GREEN GROWTH IN AFRICA	43
3.1 Introduction	43
3.2 Literature Review	47
3.2.1 Green innovation and green growth.....	47
3.2.2 Renewable energy and green growth	48
3.2.3 Institutional quality and green growth	50
3.3 Methodology	52
3.3.1 Data	52
3.3.2 Econometrics models	54
3.3.3 Cross-sectional dependency	55

3.3.4 Slope homogeneity	55
3.3.5 Unit-root test	56
3.3.6 Cointegration test	57
3.3.7 Estimation technique	58
3.3.8 Robustness check	60
3.3.9 Causality test	60
3.4 Result and Discussion.....	61
3.4.1 Descriptive statistics.....	61
3.4.2 Econometric result and discussion	62
3.4.3 Robustness check with alternative models.....	68
3.5 Conclusion and Policy Implications	70
4. SYMMETRIC AND ASYMMETRIC EFFECTS OF ECONOMIC POLICY UNCERTAINTY, OIL PRICE SHOCKS, AND FDI ON ENVIRONMENTAL SUSTAINABILITY IN SELECTED SUB- SAHARAN AFRICAN COUNTRIES.....	73
4.1 Introduction	73
4.2 Literature Review	80
4.2.1 Epu and environmental sustainability	80
4.2.2 Oil price and environmental sustainability.....	84
4.2.3 Fdi and environmental sustainability	88
4.3 Methodology.....	91
4.3.1 Data	91
4.3.2 Model specification	92
4.3.3 Estimation technique	93
4.3.3.1 Ardl approach.....	93
4.3.3.2 Nardl approach	95
4.3.3.3 Cross-sectional dependency test.....	97
4.3.3.4 Slope heterogeneity test	98
4.3.3.5 Unit-root test	100
4.3.3.6 Cointegration test	101
4.4 Result and Discussion.....	103
4.4.1 Descriptive statistics.....	103
4.4.2 Correlation.....	107
4.4.3 The symmetric result and discussion	109
4.4.3.1 Epu and environmental sustainability	109
4.4.3.2 Oil price and environmental sustainability.....	113
4.4.3.3 Fdi and environmental sustainability	114
4.4.3.4 Control variables and environmental sustainability	115
4.4.4 Asymmetric result and discussion.....	116
4.4.4.1 Epu and environmental sustainability	117
4.4.4.2 Oil price and environmental sustainability.....	121
4.4.4.3 Fdi and environmental sustainability	122
4.4.5 Robustness check	124
4.5 Conclusion and Policy Implications	125
REFERENCES	129
APPENDICES	159
APPENDIX A	159
CURRICULUM VITAE	167

ABBREVIATIONS

AMG	: Augmented Mean Group
ARDL	: Autoregressive Distributed Lag
CIPS	: Cross-Sectionally Augmented IIm, Pesaran, and Shin
CD	: Cross-Sectional Dependency
CO₂	: Carbon Dioxide Emissions
DFE	: Dynamic Fixed Effects Estimator
ECT	: Error Correction Term
EKC	: Environmental Kuznets Curve
EPU	: Economic Policy Uncertainty
FE	: Fixed Effects
GDP	: Gross Domestic Product
GMM	: Generalized Method of Moments
MG	: Mean Group Estimator
NARDL	: Nonlinear Autoregressive Distributed Lag
OLS	: Ordinary Least Squares
PCA	: Principal Component Analysis
PMG	: Pooled Mean Group Estimator
RE	: Random Effects
SDG	: Sustainable Development Goal
SSA	: Sub-Saharan Africa



SYMBOLS

β_1	: Coefficient of independent variables
i	: Country
t	: Time
N	: Number of observations
$\hat{\rho}_{ij}^2$: Correlation coefficient between residuals.
Δ_{hp}	: Tilde delta
$\Delta_{hp/I}$: Adjusted tilde delta.
J	: Lag length
α_j	: Autoregressive parameters.
ε_{it}	: Error term.
θ_{ij}^t	: Covariance coefficient
\tilde{S}	: Covariance Matrix
Y_{it}	: Vector of independent variable
X_{it}	: Vector of dependent variables
δ_i	: Speed of adjustment



LIST OF TABLES

	<u>Page</u>
Table 2.1 : Variables, symbols, measurements, sources.	20
Table 2.2 : Descriptive statistics	23
Table 2.3 : Correlation matrix	25
Table 2.4 : Linear and nonlinear impact of globalization and its sub indices on carbon emission in Africa	29
Table 2.5 : The linear and nonlinear impact of financial development and its sub indices on carbon emission in Africa.....	34
Table 2.6 : The moderate effect of globalization and financial development and carbon emission in Africa	36
Table 3.1 : PCA regression for institutional quality variables	53
Table 3.2 : Study variables, code, measurement, and source.....	53
Table 3.3 : Descriptive Statistics.....	61
Table 3.4 : Cross-sectional dependency and slope homogeneity test	62
Table 3.5 : CADF and CIPS test result	63
Table 3.6 : Westerlund (2007) cointegration test result.....	63
Table 3.7 : PMG, MG and DEF results (1,1,1,1,1,1,1,1).....	65
Table 3.8 : GMM, FE and AMG results	68
Table 3.9 : Results of the Dumitrescu-Hurlin panel causality test.....	69
Table 4.1 : Variables, symbols, measurements, and sources	92
Table 4.2 : CD test result.....	98
Table 4.3 : Slope homogeneity test results.....	99
Table 4.4 : Unit-root test result	101
Table 4.5 : Cointegration test result	102
Table 4.6 : Descriptive statistics	104
Table 4.7 : Correlation matrix	108
Table 4.8 : Symmetric PMG Estimation results	111
Table 4.9 : Walda test result.....	117
Table 4.10 : Asymmetric PMG estimation result.....	119
Table 4.11 : Residual unit-root test for symmetric PMG/ ARDL Model	124
Table 4.12 : Residual unit-root test for asymmetric PMG/ ARDL Model.....	124
Table A.1 : List of countries.....	160
Table A.2 : The linear and nonlinear effect of globalization on carbon emission in Africa: OLS fixed effects result.....	161
Table A.3 : The linear and nonlinear effect of financial development on carbon emission in Africa: OLS fixed effects results	163
Table A.4 : The moderate effect of globalziation and financiak development on carbon emission in Africa: OLS fixed effects results	164



LIST OF FIGURES

	<u>Page</u>
Figure 2.1 : Economic growths of selected economic regions (1992-2021).	9
Figure 2.2 : Bivariate regression analysis.	24
Figure 3.1 : Africa's and world GDP growth rate (2000 to 2021).....	45
Figure 3.2 : Africa's CO ₂ emissions in millions of tons (2000 to 2021).....	46
Figure 4.1 : Ecological footprint consumption in Sub-Sahara Africa (1991-2023)..	77
Figure 4.2 : CO ₂ emissions in Sub-Sahara Africa (1991-2023).....	77
Figure 4.3 : Annual average oil price (1991-2023).....	78
Figure 4.4 : Economic policy uncertainty index (1991 - 2023). ...	79
Figure 4.5 : Foreign direct inflow inflow in Sub-Sahara Africa (1991 - 2023).....	79
Figure 4.6 : Circular correlation graph.	107



ANALYSIS ON ENVIRONMENT AND ECONOMIC DEVELOPMENT IN AFRICA

SUMMARY

Africa faces a critical challenge balancing rapid economic growth and safeguarding its rich environmental resources. This PhD dissertation explores the nexus between economic growth and African environmental sustainability. We investigate how globalization, financial development, renewable energy, green innovation, institutional quality, and external shocks affect this balance. The study will help policymakers design approaches that enhance economic progress and environmental conservation as a foundation for sustainable development on the continent. The dissertation is organized into three chapters, each addressing a critical aspect of the relationship between the environment and African economic development.

In the first chapter, we examine the effect of globalization and financial development on carbon emissions in 52 African countries from 1997 to 2021. We use the two-step system Generalized Method of Moments (GMM) to analyze how different dimensions of globalization (economic, political, and social) and components of financial development (financial institutions and markets) affect environmental outcomes. The linear analysis shows that globalization and financial development increase carbon emissions, mainly through trade expansion, industrialization, and economic integration. Financial institutions also drive these emissions, but financial markets have a negligible impact, likely because they focus little on green sectors in Africa. However, we find complex dynamics when considering non-linear analysis. For economic and social globalization, as well as financial development, we observe an inverted u-shaped relationship consistent with the Environmental Kuznets Curve (EKC). Political globalization, on the other hand, follows a different path, showing a u-shaped relationship.

The second chapter examines the impact of green innovation, renewable energy, and institutional quality on green growth in 49 African countries from 2000 to 2021. In this study, we develop a unique model of green growth for Africa's context. This model integrates three dimensions of sustainable development (economic, environmental, and institutional) into one framework to provide a holistic perspective on sustainable development. We find that green innovation, renewable energy adoption, institutional quality, GDP per capita, and trade openness significantly drive long-term green growth, using Pooled Mean Group (PMG), Mean Group (MG), and Dynamic Fixed Effects (DFE) models. On the other hand, FDI and natural resource depletion are detrimental to green growth, demonstrating the dangers of reliance on resource extraction and environmentally destructive investments. In the short run, however, only institutional quality and GDP per capita positively affect green growth, while natural resource rents have a negative impact. These findings reveal the promise of renewable energy and green innovation, as well as the key role governance frameworks can play in supporting them. This chapter contributes to the broader discourse on sustainable development by introducing a tailored model for Africa's

green growth and offers a practical framework for addressing Africa's specific challenges.

In the third chapter, we examine the symmetric and asymmetric effects of external economic shocks—economic policy uncertainty (EPU), oil price fluctuations, and foreign direct investment (FDI)—on environmental sustainability in 10 Sub-Saharan African (SSA) countries from 1991 to 2023. To measure environmental sustainability, we use two critical indicators: carbon emissions and the ecological footprint, which capture both direct and indirect environmental pressures. We use Autoregressive Distributed Lag (ARDL) and Nonlinear Autoregressive Distributed Lag (NARDL) models to analyze how these shocks impact sustainability in the short and long run. We find that EPU raises ecological footprints in the short run because green investments are delayed, but symmetrically reduces them in the long run as stability facilitates more consistent policy implementation. Additionally, we find that the effects of oil price shocks are symmetrical in the long run.

The results reveal that higher oil prices result in a reduction in emissions and ecological footprints, as they help promote clean energy. Lower prices, conversely, encourage environmental harm because they further support dependence on fossil fuels. Similarly, in the longer term, FDI leads to lower emissions, likely because cleaner technologies are adopted, but in the short term, it raises emissions as industries grow. An asymmetric analysis shows that positive changes in EPU and FDI increase environmental pressures, while negative changes reduce these pressures. An adverse oil price shock raises environmental impacts, while a positive shock reduces them. These findings underscore the need for adaptive and region-specific policies to handle external shocks and direct investments toward sustainable outcomes.

Overall, this dissertation offers a comprehensive understanding of the relationship between economic growth and environmental sustainability in Africa. In the second chapter, we uniquely model green growth, and in the third chapter, we use dual environmental indicators to provide an innovative approach to promoting sustainable development suited to Africa's context. We find that economic, environmental, and institutional dimensions are interconnected and that targeted interventions can lead to long-term sustainability. This work contributes to the global discourse on sustainability and provides a practical roadmap for African policymakers to balance growth with ecological preservation. With its unique opportunities and challenges, Africa can embark on a greener, more resilient future and become a leader in the global fight against climate change.

AFRİKA'DA ÇEVRE VE İKTİSADİ GELİŞME ÜZERİNE ANALİZLER

ÖZET

Afrika, hızlı ekonomik büyüme ile doğal kaynaklarını koruma politikaları arasında kritik bir denge kurma ihtiyacıyla karşı karşıyadır. Birçok Afrika ülkesi, son yirmi ila otuz yıllık periyotlarda ortalama %5'in üzerinde yıllık GSYH büyüme oranları yakalamıştır. Temel olarak bu büyüme; şehirleşme, küreselleşme, teknolojik yenilikler ve yabancı yatırımların artışı gibi unsurlardan kaynaklanmaktadır. Ayrıca, iş gücüne katılabilecek genç nüfus, genişleyen tüketici pazarları ve zengin doğal kaynaklar Afrika'yı küresel yatırımlar için cazip bir bölge haline getirmiştir. Öte yandan, yaşanan bu ekonomik büyümeler çevresel tahribata neden olmuştur. Orman örtüsünün kaybı, karbon emisyonlarındaki artış, kirlilik ve doğal kaynakların aşırı kullanımı ciddi tehditler oluşturmaktadır. Örneğin, Afrika'da her yıl yaklaşık 3,9 milyon hektarlık orman örtüsü kaybı yaşanmakta, bu da biyoçeşitliliği azaltmakta ve iklim değişikliği risklerini artırmaktadır. Ayrıca, büyük şehirlerdeki hava kalitesi genellikle Dünya Sağlık Örgütü (WHO) standartlarının altında olup milyonlarca insanın sağlığını olumsuz etkilemektedir.

Bu bağlamda, bu doktora tezi, ekonomik büyüme ile çevresel sürdürülebilirlik arasındaki dinamikleri Afrika özelinde incelemeyi amaçlamaktadır. Tez üç ana başlık altında planlanmıştır. Bunlar; küreselleşme ve finansal gelişmenin karbon emisyonları üzerindeki etkisi, yeşil inovasyon, yenilenebilir enerji ve kurumsal kalite ile yeşil büyüme arasındaki ilişki ve ekonomik politika belirsizliği, petrol fiyat dalgalanmaları ve yabancı yatırımlar gibi dış ekonomik şokların çevresel sürdürülebilirlik üzerindeki etkileri.

Birinci bölümde, 1997-2021 yılları arasında 52 Afrika ülkesinde küreselleşme ve finansal gelişmenin karbon emisyonlarına etkisini incelemektedir. Araştırma, ekonomik büyüme ve karbon emisyonları arasındaki ilişkiyi analiz ederken, küreselleşme ve finansal gelişmenin bu ilişki üzerindeki düzenleyici rolünü de değerlendirmektedir. Analiz için sabit etkiler ve iki aşamalı sistem-genelleştirilmiş momentler yöntemi kullanılmıştır. Bulgular, ekonomik büyümenin başlangıçta enerji yoğun faaliyetler nedeniyle karbon emisyonlarını artırdığını ancak ekonomiler geliştikçe emisyonların azalabileceğini göstermektedir. Bu durum, Çevresel Kuznets Eğrisi (EKC) hipotezini destekler niteliktedir. Ayrıca, enerji tüketimi ve nüfus büyüklüğü karbon emisyonlarının önemli belirleyicileridir. Küreselleşme ve finansal gelişme genel olarak emisyonları doğrusal bir şekilde artırmaktadır. Ancak, ekonomik ve sosyal küreselleşmenin kare değerleri ters u şeklinde bir ilişki sergileyerek küreselleşmenin sürdürülebilirliği teşvik etme potansiyeline işaret etmektedir. Finansal gelişme de benzer şekilde EKC hipotezine uygun olarak kare değerlerinde negatif bir ilişki göstermektedir. Bununla birlikte, küreselleşme ve finansal gelişmenin ekonomik büyüme ile karbon emisyonları arasındaki ilişkiyi düzenleyici bir rol oynadığı görülmektedir. Bu durum, Afrika'nın kalkınma sürecinde hedefe yönelik politikaların ve sürdürülebilir uygulamaların önemini vurgulamaktadır. Araştırmanın

ampirik bulgularına dayanarak, politika önerileri birkaç ana başlık altında sıralanabilir. İlk olarak, küreselleşme ve finansal gelişmenin doğrusal etkileri ele alınmalıdır. Ekonomik küreselleşme bağlamında, sanayilerin temiz teknolojileri ve sürdürülebilir uygulamaları benimsemesini teşvik etmek amacıyla çeşitli teşvik mekanizmaları uygulanmalıdır. Bunun yanı sıra, çevresel zararları önlemek için sıkı çevresel regülasyonlar devreye alınmalıdır. Politik küreselleşmenin karbon emisyonları üzerindeki etkilerini yönetebilmek adına güçlü iç yönetim sistemleri oluşturulmalı ve uluslararası iş birliği ağları güçlendirilmelidir. Böylece, kirlilik cenneti etkisi gibi olumsuz sonuçlar engellenebilir. Sosyal küreselleşme bağlamında ise çevre bilincinin artırılması büyük önem taşımaktadır. Toplumsal girişimler, yeşil tüketim alışkanlıklarının teşviki ve çevre eğitimi programları bu amaçla kullanılabilir. Ayrıca, finansal gelişmenin sürdürülebilirliği sağlamak için finansal kurumlar yeşil yatırımları ve kredileri teşvik etmeli, yenilikçi finansal mekanizmalar aracılığıyla yenilenebilir enerji projelerine destek vermelidir.

Doğrusal olmayan etkiler dikkate alındığında ise, ekonomik ve sosyal küreselleşme ile finansal gelişmenin ters u şeklindeki ilişkisinin yönetilmesi kritik bir politika alanıdır. Bu süreçte, sürdürülebilir teknolojilerin ve yatırımların erken aşamalarda teşvik edilmesi hayati öneme sahiptir. Politik küreselleşmenin u şeklindeki etkisi ise uluslararası anlaşmalar yoluyla çevresel düzenlemelerin sıkılaştırılmasıyla dengelenebilir. Ayrıca, yeşil finansal araçların geliştirilmesi ve bu araçların yaygınlaştırılması sürdürülebilirlik açısından önemli bir katkı sağlayacaktır. Son olarak, ekonomik büyüme ve karbon emisyonları arasındaki ilişki yeniden şekillendirilebilir. İleri ve temiz teknolojilerin yaygınlaşmasını teşvik etmek için vergi indirimleri ve hibeler gibi mali teşvikler sağlanmalıdır. Bunun yanı sıra, sürdürülebilir tedarik zinciri yönetimi, emisyon azaltım standartları veya gönüllü anlaşmalar yoluyla desteklenmelidir. Finansal kurumların sorumlu yatırımlar yapmasını sağlamak için sıkı düzenleyici çerçeveler oluşturulmalı ve yeşil projelerle iş birliği yapan işletmeler, ortak kredilendirme ve araştırma girişimleri ile desteklenmelidir. Bu adımlar, Afrika'nın karbon emisyonlarını azaltarak sürdürülebilir bir kalkınma yoluna girmesini kolaylaştıracaktır.

2000-2021 yılları arasında 49 Afrika ülkesini kapsayan, yeşil inovasyon, yenilenebilir enerji ve yeşil büyüme başlıklı ikinci bölümde, yeşil inovasyon, yenilenebilir enerji kullanımı ve kurumsal kalitenin uzun vadede yeşil büyümeyi desteklediği ortaya konulmaktadır. Afrika'nın bağlamına özgü geliştirilen yeşil büyüme modeli, ekonomik, çevresel ve kurumsal boyutları entegre ederek sürdürülebilir kalkınmaya yönelik bütüncül bir çerçeve sunmaktadır. Yeşil büyüme, ekonomik refahı artırırken çevrenin korunmasını sağlayarak ekonomik kalkınma için bütüncül bir strateji sunmaktadır. Bu nedenle, yeşil büyüme sürdürülebilir kalkınma için kritik bir paradigma olarak ortaya çıkmıştır. Bu çalışmada, Afrika'da yeşil büyümeyi etkileyen kısa ve uzun vadeli faktörler incelenmektedir. Çalışma, özellikle kurumsal kalite, yeşil inovasyon ve yenilenebilir enerji tüketimine odaklanırken, kişi başına düşen GSYH, ticaret serbestleşmesi, doğrudan yabancı yatırımlar (FDI), nüfus büyüklüğü ve doğal kaynak gelirlerinin etkilerini de değerlendirmektedir. Bulgular, güçlü kurumların kısa ve uzun vadeli yeşil büyümeyi desteklemede kritik bir rol oynadığını göstermektedir. Yeşil inovasyonun kısa vadede negatif ve istatistiksel olarak önemsiz bir etkisi bulunurken, uzun vadede pozitif ve istatistiksel olarak anlamlı bir etkisi olduğu görülmüştür. Bu durum, uzun vadeli yatırım stratejilerinin önemine işaret etmektedir. Yenilenebilir enerjinin uzun vadede maliyet azalmasıyla yeşil büyümeyi desteklediği bulunmuş, ancak kısa vadede başlangıç maliyetleri ve altyapı talepleri nedeniyle

olumsuz etkiler gözlemlenmiştir. Ticaretin etkisine gelince bu değişken karmaşık bir tablo sunmaktadır. Kısa vadede ticaret serbestleşmesi çevresel bozulmaya neden olabilirken, uzun vadede ticaretin bilgi transferi ve daha sıkı çevresel standartlar aracılığıyla faydalar sağladığı ortaya çıkmıştır. Doğrudan yabancı yatırımlar, uzun vadede negatif ve anlamlı bir etkiye sahiptir, bu da kirlilik cenneti hipotezi ile uyumludur. Doğal kaynak gelirleri ise hem kısa hem de uzun vadede yeşil büyümeyi engelleyen bir faktör olarak öne çıkmaktadır. Kişi başına düşen GSYH, hem kısa hem de uzun vadede yeşil büyüme ile pozitif ve anlamlı bir ilişki göstermektedir. Kısa vadede negatif ve önemsiz bir etkiye sahip olan nüfus artışı ise, uzun vadede pozitif ve anlamlı bir etki göstermektedir. Bu durum, nüfus baskısının inovasyonu ve sürdürülebilir uygulamaları teşvik edebileceğini ve bu yolla yeşil büyümeyi destekleyebileceğini düşündürmektedir.

Bu bulgular ışığında ilk olarak, sağlam ve şeffaf kurumlara yatırım yapmak, uzun vadeli yeşil büyüme stratejileri için istikrarlı ve öngörülebilir bir ortam yaratmak açısından hayati önem taşımaktadır. Bu, düzenleyici çerçevelerin güçlendirilmesini, iyi yönetişimin teşvik edilmesini ve sürdürülebilir kalkınma için kamu-özel sektör ortaklıklarının desteklenmesini içermelidir. İkinci olarak, başlangıçtaki zorluklara rağmen, yeşil inovasyona uzun vadeli yatırımlar yapılması kritik öneme sahiptir. Bu bağlamda, araştırma, geliştirme ve bu sektörde ticarileşmeyi destekleyen uzun vadeli politikalar teşvik edilmelidir. Bu teşvikler, vergi indirimleri, hibeler ve yeşil teknolojilere odaklanan kamu-özel sektör ortaklıklarını içerebilir. Üçüncü olarak, yenilenebilir enerji altyapısına yönelik uzun vadeli yatırımlar öncelikli hale getirilmelidir. Maliyet endişelerini gidermek için hedefe yönelik politikalar, örneğin sübvansiyonlar veya sabit tarife sistemleri, geçiş sürecini hızlandırabilir. Dördüncü olarak, ticaret serbestleşmesinden kaynaklanabilecek kısa vadeli çevresel bozulmayı azaltmak için çevresel sürdürülebilirliği önceliklendiren ticaret anlaşmaları teşvik edilmelidir. Bu anlaşmalar, bilgi transferini kolaylaştırmalı ve ticaret ortakları arasında daha sıkı çevresel standartlar oluşturmalıdır. Beşinci olarak, doğrudan yabancı yatırımların çevresel etkilerini dikkatle değerlendirmek ve bu yatırımların ulusal yeşil büyüme stratejileriyle uyumlu olmasını sağlamak önemlidir. Kirlenici endüstrileri çekmekten kaçınmak için dikkatli bir yaklaşım benimsenmelidir. Altıncı olarak, ekonomik büyümeyi sürdürülemez kaynak kullanımından ayırmak için kaynak verimliliğini ve çeşitlendirmeyi teşvik eden politikaların uygulanması kritik öneme sahiptir. Bu, alternatif gelir kaynaklarının keşfedilmesi, yeşil teknolojilere yatırım yapılması ve sürdürülebilir kaynak yönetimi uygulamalarının benimsenmesini içerebilir. Son olarak, nüfus artışının inovasyon ve sürdürülebilir uygulamaları teşvik etme potansiyelini kabul etmekle birlikte, sorumlu kaynak yönetimini teşvik eden politikaların geliştirilmesi gerekmektedir. Bu, eğitim yatırımlarını, aile planlaması girişimlerini ve sürdürülebilir kentsel kalkınmayı teşvik etmeyi içerebilir.

1991-2023 yılları arasında 10 Sahra-Altı Afrika ülkesini kapsayan, dış ekonomik şokların çevresel sürdürülebilirliğe etkileri başlıklı üçüncü bölümde, ekonomik politika belirsizliği (EPU), petrol fiyat dalgalanmaları ve doğrudan yabancı yatırımların çevresel sürdürülebilirlik üzerindeki simetrik ve asimetrik etkilerini analiz etmektedir. Çevresel sürdürülebilirlik, karbon emisyonları ve ekolojik ayak izi göstergeleriyle ölçülmüştür.

Bulgular EPU, petrol fiyatları ve FDI'nın çevresel sürdürülebilirlik üzerinde anlamlı etkileri olduğunu, ancak bu etkilerin kısa ve uzun vadede farklılık gösterdiğini ortaya koymaktadır. Simetrik olarak, EPU'nun kısa vadede ekolojik ayak izini artırdığı, ancak uzun vadede azalttığı bulunmuştur. Petrol fiyatları ise uzun vadede karbon

emisyollarını ve ekolojik ayak izini azaltırken, kısa vadede etkisizdir. FDI ise uzun vadede karbon emisyonlarını azaltırken, kısa vadede artırmaktadır. Ekolojik ayak izi üzerinde FDI'nın simetrik bir etkisi bulunmamaktadır. Asimetrik analizler, EPU ve FDI'daki olumlu değışimlerin emisyonları ve ekolojik ayak izini artırdığını, olumsuz değışimlerin ise her ikisini azalttığını göstermektedir. Petrol fiyat şoklarının ise pozitif şoklarla emisyonları azalttığını, negatif şoklarla ise artırdığını bulunmuştur. Bu bulgular doğrultusunda ilk olarak, artan EPU'ya yanıt olarak, Sahra-Altı Afrika (SSA) hükümetleri kısa vadede kaynak kullanımını sınırları, daha sıkı çevresel etki değerlendirme (EIA) prosedürleri ve enerji verimli teknolojileri benimsemek için teşvikler içeren geçici koruma önlemleri almalıdır. Uzun vadede, yenilenebilir enerji altyapısına yatırımlar ve karbon fiyatlandırma mekanizmalarının (karbon vergileri veya kota ticareti sistemleri gibi) uygulanması, fosil yakıtlara olan bağımlılığı azaltacak ve karbon emisyonlarını düşürecektir. EPU'nun asimetrik etkileri, politika yapıcılarının dayanıklılık odaklı stratejiler benimsemesini gerektirmektedir. EPU yüksek olduğunda, hükümetler daha sıkı emisyon sınırları koymalı ve düşük karbonlu teknolojilerin kullanılmasını zorunlu hale getirmelidir. EPU düşük olduğunda ise yeniden ağaçlandırma, arazi rehabilitasyonu ve biyolojik çeşitliliğin korunması önceliklendirilmelidir. Ekolojik riskleri tamponlamak ve ekonomik dalgalanmalar sırasında sürdürülebilir yatırım akışlarını sürdürmek için istikrar fonları kurulmalıdır. Petrol fiyatları dinamikleri, SSA hükümetlerinin yüksek petrol fiyatlarını yenilenebilir enerjiye geçişi hızlandırmak için bir fırsat olarak değerlendirmesi gerektiğini göstermektedir. Bu, temiz enerji altyapısına yatırımlar, yenilenebilir enerji teşvikleri ve kırsal bölgeler için şebeke dışı çözümler geliştirilmesini içerir. Önde gelen petrol ihracatçıları (örneğin Nijerya, Sudan ve Angola), petrol gelir fazlasını enerji verimli ulaşım, elektrifikasyon programları ve temiz pişirme teknolojileri gibi yeşil yatırımlara yönlendiren fonlara ayırmalıdır. FDI'nın çevresel faydalarını en üst düzeye çıkarmak için SSA hükümetleri, özellikle karbon yoğun sektörlerde (örneğin, imalat ve madencilik) yabancı yatırımcılardan temiz teknolojiler ve enerji verimli üretim sistemlerini benimsemelerini talep etmelidir. Karbon vergileri veya kota ticareti gibi karbon fiyatlandırma mekanizmaları, emisyon azaltımını ödüllendirmeli ve bu gelirler yenilenebilir enerji altyapısına ve çevresel restorasyon projelerine yönlendirilmelidir. Uzun vadede, hükümetler, yeşil FDI'ı teşvikler (örneğin vergi indirimleri, sübvansiyonlar ve yenilenebilir enerji, temiz üretim ve sürdürülebilir altyapı için tercihli finansman) aracılığıyla çekmeyi hedeflemelidir. Ayrıca, FDI dalgalanmalarını kontrol altına almak için sektör bazlı düzenlemeler gerekli olup, artış dönemlerinde daha yüksek standartlar uygulanmalı, düşüş dönemlerinde ise restorasyon programları teşvik edilmelidir.

1. INTRODUCTION

The African pursuit of economic growth and environmental sustainability involves significant tradeoffs and opportunities. Over the past decades, economic growth across the continent has been substantial, with many countries achieving annual GDP growth rates exceeding 5%. This development has been driven by urbanization, globalization, technological advancements, and increased foreign investment (Batrancea et al., 2021). Africa's young workforce, growing consumer markets, and natural resources have also attracted global interest and investments.

However, this economic growth has led to environmental degradation, including increased emissions, resource depletion, and pollution. For instance, Africa loses approximately 3.9 million hectares of forest cover annually, resulting in biodiversity loss and heightened climate change risk (FAO, 2020). Air quality in many major cities fails to meet World Health Organization (WHO) standards, adversely affecting millions of people's health.

The effects of climate change amplify these issues, disproportionately affecting Africa despite its minimal contribution to global emissions. For instance, the frequency of extreme weather events—droughts, floods, and heatwaves—has risen dramatically, jeopardizing food security in regions where over 60% of the population depends on agriculture (IPCC, 2022). Sea level rise has also intensified risks for coastal communities, displacing populations and threatening vital economic hubs in many parts of Africa.

Globalization offers opportunities to integrate Africa into the global economic landscape, fostering trade expansion and enabling foreign direct investment (FDI) and technological diffusion. Initiatives like the African Continental Free Trade Area (AfCFTA) aim to reduce trade barriers and enhance regional economic integration (UNECA, 2021). Similarly, external initiatives such as the Turkish Cooperation and Coordination Agency (TIKA) and the Chinese Belt and Road Initiative (BRI) have improved infrastructure development. However, globalization also poses

environmental risks, as the rising global demand for African commodities drives unsustainable resource extraction, deforestation, habitat destruction, and increased carbon emissions.

In parallel, financial development has also played an essential role in facilitating access to credit and financial resources, infrastructure projects, and industrial expansion in Africa. While these investments support economic growth, their environmental implications vary. Financial systems have fostered green innovation, such as cleaner production methods and renewable energy projects (Antwi et al., 2024). However, weak environmental regulations have allowed investments in resource-intensive and polluting industries, exacerbating ecological degradation. Aligning financial development with sustainability goals is crucial to promoting investments that enhance green growth rather than harm the environment.

Green innovation holds immense potential to address Africa's environmental and economic challenges. However, the continent faces significant barriers, including limited financial resources, inadequate infrastructure, and insufficient investment in research and development (Chukwu, 2020; Khurshid et al., 2024). Many rural communities, which constitute a large proportion of the population, lack access to green technologies and expertise.

Renewable energy represents a significant opportunity for transitioning to a sustainable, low-carbon economy in Africa. Expanding the use of solar, wind, and hydropower resources across the continent can substantially reduce dependence on fossil fuels (Bishoge et al., 2020). For instance, countries such as South Africa, Morocco, and Ethiopia have increased their renewable energy generation, thereby improving electricity access in regions with little or no supply. However, the large-scale deployment of renewable energy faces several challenges in the continent, including high costs, inadequate infrastructure, and the need for supportive policies (Chukwuemeka et al., 2023). Addressing these barriers will require international partnerships and investments to accelerate Africa's transition to renewable energy.

To this end, sound governance, policies, and proper legal frameworks are crucial for sustainable development. On the other hand, lack of strong institutions, corruption, and enforcement of environmental laws are some challenges that are still prevalent in many African countries. Enhancing institutional capacity can enhance green growth

and help in luring sustainable investments. Sound governance ensures that financial development is in harmony with environmental goals, thus neutralizing the effects of globalization and industrialization.

Also, external factors, including economic policy uncertainty, oil price volatility, and foreign direct investment, impact Africa's environmental sustainability. Economic policy uncertainty can sometimes hamper ecological stewardship by destabilizing the environment for investment. At the same time, oil price volatility determines the energy consumption patterns, which either boost or hinder the shift towards renewable energy. Likewise, foreign direct investment has a dual effect on the environment in that it has both positive and negative impacts on the environment. Investments in green technologies can help to decrease carbon emissions while, on the other hand, resource-intensive projects such as mining and oil exploitation worsen environmental impacts. Therefore, policymakers should implement measures that will help minimize the adverse effects of these shocks while at the same time maximizing the opportunities that they present to support sustainability.

Much of the existing literature on the relationship between economic growth and environmental sustainability focuses on developed nations, leaving a significant gap in understanding Africa's context. Thus, this dissertation systematically examines the interplay between globalization, financial development, green innovation, renewable energy, external economic shocks with environmental performance and providing a comprehensive analysis of sustainable development in Africa. This dissertation is organized into three chapters, each addressing a distinct but interconnected aspect of sustainable development in Africa.

Chapter one explores the linear and nonlinear effects of globalization and financial development on economic and environmental outcomes across 52 African countries from 1997 to 2021, highlighting the thresholds at which these factors lead to transitions from a growth-enhancing to an environmentally harmful force and vice versa. Chapter two examines the roles of green innovation, renewable energy, and institutional quality in fostering green growth in 49 African countries from 2000 to 2021, emphasizing the synergistic relationship between governance and green technologies. Chapter three discusses the role of external shocks such as economic policy uncertainty (EPU), oil price volatility, and FDI inflows on the environmental sustainability of 10 SSA countries from 1991 to 2023.

To achieve these objectives, we employ advanced econometric analyses tailored to the specific conditions of each chapter. The first chapter uses fixed effects and system GMM estimators to explore the linear and nonlinear relationships between globalization, financial development, and carbon emissions. The second chapter applies pooled mean group (PMG), mean group (MG), and dynamic fixed effects (DFE) estimators to examine the short- and long-run relationships between green innovation, renewable energy, and institutional quality. The third chapter employs autoregressive distributed lag (ARDL) and nonlinear autoregressive distributed lag (NARDL) estimators to evaluate the symmetric and asymmetric impacts of economic policy uncertainty (EPU), oil price shocks, and foreign direct investment (FDI) on the environmental sustainability.

These methods use data from well-known international databases. Key sources include the World Bank Development Indicators (WDI), International Monetary Fund (IMF) Financial Statistics, KOF Globalization Index, International Energy Agency (IEA), World Governance Indicators (WGI), Organization for Economic Cooperation and Development (OECD), Global Footprint Network, and the Economic Policy Uncertainty (EPU) Index. Together, these datasets cover important factors needed to understand sustainable development in Africa.

The findings of this dissertation offer valuable insights into the dynamics of economic and environmental tradeoffs in the African context. Chapter one reveals that carbon emissions increase with economic growth, energy consumption, and population size. Also, the finding supports the Environmental Kuznets Curve (EKC) hypothesis in Africa. The study further indicates that globalization and its sub-indices, financial development, and financial institutions contribute linearly to increasing carbon emissions. In contrast, financial markets have a negligible effect. Nonlinear results show that the squared terms of globalization, its economic and social subindices, and financial development and its subindices exhibit a negative impact, reflecting an inverted U-shaped association with carbon emissions. In contrast, political globalization follows a U-shaped trend. Additionally, the study highlights that globalization, financial development, and their subindices play a moderating role in carbon emissions.

Chapter two demonstrates that green innovation and renewable energy consumption, institutional quality, GDP per capita, trade openness, and population growth have

positive long-run effects on green growth. On the other hand, FDI and natural resource depletion are adverse. In the short run, only ins, institutional quality, and GDP per capita positively impact growth, while natural resource rent has a negative impact.

Chapter three reveals that EPU increases the ecological footprint in the short run but reduces it in the long run. Oil prices also reduce carbon emissions and ecological footprints in the long term but have no short-term impact. In contrast, FDI increases carbon emissions in the short run but reduces them in the long run. The analysis also points out significant asymmetries in the impact of these factors. Positive changes in EPU and FDI increase emissions and ecological pressures, whereas negative changes reduce them. Furthermore, the effect of oil price shocks on emissions and ecological footprints is inversely proportional to the direction of the shock.

These findings highlight the need for comprehensive and flexible policy measures to support sustainable development in Africa. Policymakers should also work on the risks associated with globalization and financial development by implementing regulatory measures that will help manage the environmental impact while harnessing the economic gains that come with these forces. It is also important that investments made in green innovation and renewable energy are accompanied by institutional changes that will improve governance and accountability of such technologies to realize their potential. Also, adaptive measures must be implemented to counteract external shocks to foster resilience and cushion the impact of economic shocks on environmental sustainability.

This dissertation contributes significantly to the existing scholarly knowledge on sustainable development by providing an empirical analysis of the relationship between economic growth and environmental protection in Africa. Based on the research findings that incorporate the concepts of globalization, green growth, and external economic influences, the study presents a systematic way to attain sustainable and inclusive growth in Africa. Therefore, the study's findings support the integrated approach to development where economic development, environmental conservation, and the development of institutional frameworks are all given equal attention.



2. EFFECT OF ECONOMIC GROWTH ON CO₂ EMISSION IN AFRICA: DO FINANCIAL DEVELOPMENT AND GLOBALIZATION MATTER?

2.1 Introduction

In recent decades, the world has been confronted with two intertwined problems: achieving economic growth and addressing the urgent issue of climate change. Economic growth has been a critical engine of progress, pulling millions out of poverty and developing societies (Zhu et al., 2022). Nonetheless, this advancement often exacts a significant toll on the environment, contributing to rising carbon emissions and aggravating the climate change problem (Nahrin et al., 2023). Carbon emissions represent the predominant greenhouse gas responsible for global warming, accounting for over 60% of global greenhouse gas emissions (EPA, 2018).

Meanwhile, increased atmospheric carbon levels negatively impact economic growth, the environment, and human health. These detrimental impacts encompass climate-related expenses, increased healthcare costs from air pollution, and disruptions to critical infrastructure (Boamah et al., 2017; Dechezleprêtre et al., 2020). Also, carbon emissions keep the Earth from cooling, which elevates temperatures in different geographies and causes irreversible climatic changes such as flooding, water scarcity, erosion, and acid rain. Excessive carbon emissions further threaten human health through polluting the air, spreading diseases, and causing food shortages (IPCC, 2019). Therefore, it has become increasingly crucial to grasp the origins of carbon emissions and their connection to economic growth (Mitić et al., 2023). Thus, this study highlights the significant role played by financial development (FD) and globalization in the intricate relationship between economic growth and carbon emissions.

The role of FD and globalization in the growth-emissions nexus is complex and multifaceted. Financial development is a vital funding source for various projects and is deeply intertwined with economic growth and environmental well-being. An effectively functioning financial sector facilitates efficient capital allocation, mobilizes savings, and encourages productive venture investments in energy-efficient technologies that aim to minimize carbon emissions (Acheampong, 2019). Moreover,

as economies progress and financial systems mature, there is an expansion in credit availability and investment opportunities (Abbas et al.,2022). This expanded access empowers entrepreneurs and businesses to engage in environmentally friendly innovation, ultimately contributing to enhanced environmental conditions (Abid et al.,2022). FD can also improve environmental quality by increasing productivity and abetting societies' access to new technologies (Aluko and Obalade, 2020). Globalization can also help to reduce carbon emissions by sharing knowledge, expertise, and best practices about sustainable practices and energy-efficient technologies (Zaidi et al., 2019).

Financial development and globalization may also have adverse impacts on environmental quality. FD can increase emissions by expanding fossil fuel-dependent industries to meet rising energy demands (Shahbaz and Lean, 2012). As countries pursue financial development, they frequently rely on nonrenewable energy to drive economic growth, even though these energy sources emit significant amounts of greenhouse gases (Awodumi and Adewuyi, 2020). This produces more carbon dioxide and contributes to climate change and environmental degradation. Also, as people's incomes increase, economic development leads to more consumption and production (Wang et al., 2020), leading to increased carbon emissions.

In addition, investments in environmental degradation driven by financial institutions prioritize maximizing profits over environmental impacts (Habiba et al., 2021), further increasing carbon emissions and causing climate change. Also, globalization has the potential to facilitate a phenomenon called "race to the bottom," wherein nations endeavor to attract investments by implementing lax environmental regulations (Acheampong, 2022). This could potentially result in a significant increase in carbon emissions. Moreover, globalization can cause more carbon emissions by increasing energy consumption (Antweiler et al., 2001) and natural resource depletion (Panayotou, 2000). Consequently, the Earth's climate has undergone disturbances, resulting in increased extreme weather phenomena, elevated sea levels, and ecological imbalances.

Financial development and globalization are probably affecting the African economies more than any other part of the world at the present economic setup. Although many African nations are classified as low-income, the continent has witnessed remarkable economic growth in recent years, establishing itself as the world's fastest-growing

region (Figure 2.1). The continent's annual average growth rate is 3.6%, above the global average of 3% for 1992- 2021 (UNCTAD, 2021). Along with economic growth, the continent is experiencing fast industrialization and urbanization. For instance, according to the OECD (2020) report, an additional 950 million city dwellers will exist in Africa by 2050.

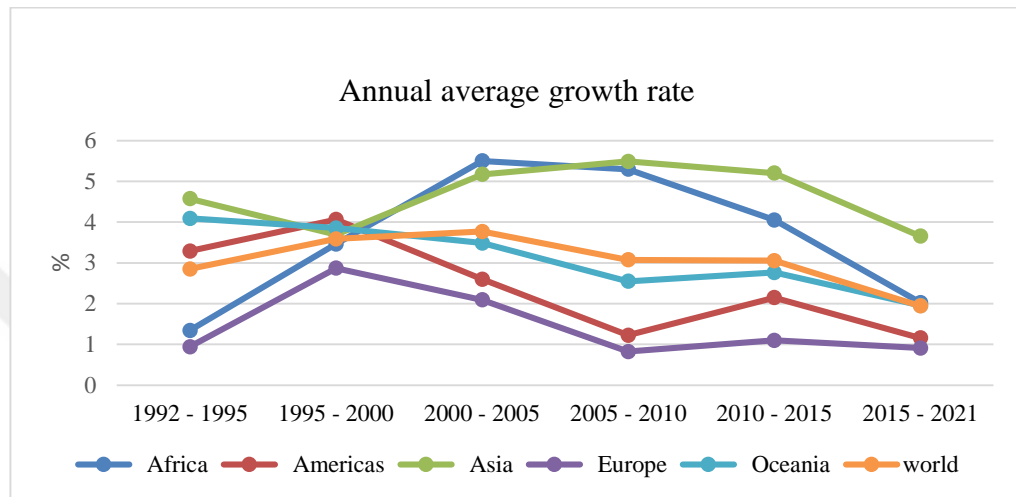


Figure 2.1 : Economic growth of selected economic regions (1992-2021).

To support and catalyze this growth, African countries have, since the 1990s, made concerted efforts to deepen, streamline, and strengthen their financial systems. However, despite these endeavors, Africa's financial system is weak and not as developed impedes the transfer of environmentally sustainable green technologies (Acheampong, 2019). Moreover, while many financial institutions in Africa contribute to economic growth, they are also likely to finance polluting projects that rely on outdated technologies, contributing to carbon emissions.

Also, globalization has brought economic benefits to Africa, with increased global income leading to greater demand for African goods and natural resources (Iyoboyi et al., 2020). However, this growing demand for resources has resulted in higher energy consumption (Aladejare, 2022), which lowers environmental quality in Africa. Furthermore, globalization is the main factor that causes deforestation, natural resource depletion, and global warming (Shahbaz et al., 2017).

Recent data and research also underscore the adverse environmental consequences of Africa's economic growth. While Africa contributes the least to global ecological pollution (only 3.8% compared to the United States' 17%, China's 23.3%, and the EU's

13.0%), carbon emissions have risen in the continent (CDP, 2020). According to Statista (2021), carbon emissions in Africa increased by 4.6% per year between 1995 and 2020, rising from 7.2 billion tons in 1995 to 11.95 billion tons in 2020, a total increase of 67.5%. Between 1990 and 2017, Africa's energy-related carbon emissions grew by 123%, which was much faster than the global average of 60%, and about 55% of the countries that have been affected by extreme environmental problems associated with Carbon emissions are from the continent (Ayompe et al., 2020; Maplecroft, 2011).

Furthermore, recent forecasts suggest that carbon emissions in Africa are projected to increase by 30% by 2050, reaching a total of 1,550 million tons (Steckel et al., 2020). This projected increase in African emissions contradicts the critical target of achieving a 32% reduction by 2030, which is essential for fulfilling UN Sustainable Development Goals and the Paris Agreement for 2050. Thus, estimating the role of globalization and FD on emissions is of utmost importance for Africa as it formulates development strategies and policies to mitigate carbon emissions. Effective participation in global climate policy agreements is crucial to address this pressing issue and ensure a sustainable future for both Africa and the world.

In this context, scholars have conducted extensive research on the influence of FD on economic growth in the continent, but there is a notable gap in the literature when it comes to considering environmental perspectives. Additionally, previous investigations into the environmental consequences of financial development often relied on a single indicator, which may not comprehensively capture the multifaceted nature of this relationship. In an attempt to overcome this limitation, Acheampong (2019) employed six distinct FD indicators to evaluate their influence on carbon emissions. Nevertheless, individual indicators might not fully encompass the intricacies of the financial structure due to their potential shortcomings in depth and accessibility (Emenekwe et al., 2022). Also, past research on globalization's environmental impact in Africa often emphasized economic aspects, using trade openness as an indicator (Acheampong et al., 2019; Gyimah et al., 2023). However, globalization encompasses a broader array of dimensions, necessitating consideration of these factors in environmental analyses. Moreover, prior studies have often failed to account for the moderating impact of globalization and FD on carbon emissions in African nations, resulting in conflicting findings. Thus, this study aims to examine

their influence, considering linear and nonlinear relationships and their potential as moderators in carbon emissions in Africa.

To accomplish our research objectives, we have put out four hypotheses that require testing: (1) Does FD and globalization exhibit linear and nonlinear effects on carbon emissions? (2) Do FD and globalization moderate carbon emissions affect growth? (3) Is “the Environmental Kuznets’s Curve (ECK) hypothesis” valid? and (4) Is there a specific threshold level of globalization and FD that reduces carbon emissions in African nations?

The contribution of this study is twofold. Firstly, our study employs an FD index created by the International Monetary Fund (IMF) rather than relying on a single FD indicator. This index comprises nine distinct metrics that collectively measure the depth, accessibility, and efficiency of FD. Each of these metrics captures specific attributes of financial markets and institutions. Secondly, instead of solely using trade openness, the study employs the KOF Globalization Index (Dreher, 2006), which categorizes globalization into economic, social, and political dimensions, providing a more comprehensive perspective.

Thirdly, this research represents a groundbreaking endeavor as it investigates both the linear and nonlinear impacts of FD and globalization on carbon emissions. Moreover, it delves into the moderating role of FD and globalization within a comprehensive panel dataset covering 52 African countries over the period from 1997 to 2021. Lastly, the study's findings yield essential policy recommendations, encouraging African governments to consider the interconnectedness of financial development, globalization, and environmental sustainability.

2.2 Literature Review

2.2.1 Economic growth and carbon emission

The role of economic growth in emissions is a complex and contentious issue in scholarly literature. Some studies suggest that carbon emissions increase or decrease proportionally with economic growth (Acheampong,2019; Barassi and Spagnolo, 2012; Li et al.,2022; Shikwambana et al.,2021). However, others have found nonlinear relationships, indicating that the relationship between the two variables is complex (Grossman and Krueger, 2010; Rahman et al., 2022; Sohag et al., 2019).

Theoretically, the growth emissions nexus has been extensively studied using the "Environmental Kuznets Curve (EKC)." The EKC was first developed by Grossman Krueger (1991) and is widely regarded as a valuable tool for understanding this relationship. The EKC assumes an inverted U relationship, which states that as economic growth increases, carbon emissions increase to a certain point, decreasing again. The EKC explanation encompasses three crucial effects: Scale, Composition, and Technique. According to the Scale effect, the early stages of economic growth require more resources and inputs to enhance production. This heightened demand consequently leads to increased energy consumption, greater pollution levels, and elevated carbon emissions.

In contrast, the Composition effect underscores the transformation that unfolds within the structure of production as an economy expands. This transformation encompasses a shift from both polluting and less polluting activities. This, in turn, has an ambiguous effect on the environment. Finally, the Technique Effect comes into play as countries' income levels increase, resulting in a shift towards a more significant share of the service sector and a decrease in heavy industry output. High-income economies also engage in more research and development, which leads to cleaner technologies and processes that help to reduce carbon emissions.

Following Grossman and Krueger (1991), several empirical studies (see, e.g. Bilgili et al., 2016; Grossman and Krueger, 2010; Rahman et al., 2022; Syed and Tripathi, 2018; Ulucak and Bilgili, 2018) have supported the notion that there is a bell-shaped association between growth and emissions, with pollution "reversing" above a certain income threshold. In general, the EKC theory concludes that environmental problems can be solved through economic growth. While several studies support the EKC hypothesis, others also question it. Some studies have found a linear relationship even after nations achieved a high-income level (Onofrei et al., 2022). Others have found that the relationship is not linear but takes a U-shaped (Sohag et al., 2019) or N-shaped form (Maduka et al., 2022).

Also, there has been a noticeable increase in academic research focusing on exploring the link between economic growth and carbon emissions in various African countries, with diverse findings and conclusions emerging from this scholarly discourse. One significant contribution to this ongoing scholarly discourse comes from the work of Anaba (2022), who conducted a recent study focusing on Sub-Saharan African

countries. Their research, encompassing data from 20 countries spanning the years 2000 to 2020, revealed a noteworthy positive correlation between economic growth and carbon emissions. Also, Esposito et al. (2021) examined 47 African countries from 1995 to 2016, uncovering various patterns, including unidirectional and bidirectional relationships between growth and emissions.

Olubusoye and Musa (2020) expanded the inquiry to 43 African countries from 1980 to 2016, finding a positive correlation in 79% of the studied nations. Additionally, Yameogo et al. (2021) explored 20 Sub-Saharan African nations, indicating a decrease in carbon emissions between 2002 and 2017. Conversely, Ouoba (2017) found no significant correlation between growth and emissions in eight West African nations from 1970 to 2010, as per the bound test and Autoregressive Distributed Lag (ARDL) results.

Numerous studies have also explored the EKC hypothesis and its applicability in various African countries, yielding diverse findings. In this regard, Maduka et al. (2022) conducted research in Nigeria using ARDL, quartile regression, and the Granger causality test approach. Their study identified an N-shaped association between economics and emissions during the period from 1990 to 2020. In support of the EKC hypothesis, Kwabena et al. (2017) found evidence in Sub-Saharan Africa (SSA), while Mulali et al. (2016) discovered supporting evidence in Kenya. Conversely, Acheampong (2019) and Zoundi (2017) and Twerefou et al. (2016) were unable to confirm the ECK hypothesis in their respective studies for SSA and Ghana.

2.2.2 Financial development and carbon emissions

With growing concerns about climate change, the link between Financial Development (FD) and carbon emissions is now being increasingly acknowledged. However, scholars disagree on the nature of this relationship. Two conflicting theories can be found in the literature, leading to an ongoing debate. The first theory asserts that FD increases carbon emissions. This theory is based on the premise that a more advanced financial system can facilitate companies' access to capital and credit (Levine, 1997). This, in turn, can lead to more investment in energy-intensive industries that rely heavily on carbon-emitting technologies (Bui, 2020). Also, a sound financial development system can create economic growth and optimism, increasing investment in energy-intensive sectors (Sadorsky, 2010). Additionally, the expansion of industries

and urbanization, known for their high levels of carbon emissions, can be facilitated by financial development (Gokmenoglu et al., 2015; Shahbaz and Lean, 2012).

A second theory asserts that FD decreases carbon emissions. According to proponents of this theory, FD can incentivize the growth and widespread use of renewable energy sources and green technologies (Dong and Akhtar, 2022). Furthermore, it enhances the accessibility of low-cost financing for individuals and companies researching and developing environmentally friendly products (Tamazian et al., 2009). FD is also essential for fostering innovation and investment and highlighting the significance of well-functioning financial markets (Mansour, 2023). Moreover, effective financial development can catalyze sustainable development and contribute to reducing carbon emissions. By promoting credit availability, attracting foreign direct investment (FDI), ensuring robust corporate governance, and facilitating technology transfer, the financial system can also help minimize economic activities' environmental impact (Acheampong, 2019; Golub et al., 2011).

Recent empirical research on FD and carbon emissions also yields contradictory and inconsistent results. While studies (see; Shoaib et al., 2020; Zaidi et al., 2019) argue for an adverse relationship, indicating that as financial development increases, carbon emissions decrease, and others (Le and Ozturk, 2020) suggest a positive relationship. Furthermore, certain studies, such as (Acheampong et al., 2019; Habiba and Xinbang, 2022), present mixed results, showing both positive and negative associations, while others, like Jamel and Maktouf (2017) find an insignificant relationship between the two variables.

In the context of Africa, several studies have investigated the relationship between FD and carbon emissions. For instance, Odhiambo (2020) Conducted an exploration of this relationship across 39 sub-Saharan African (SSA) countries using the GMM spanning from 2004 to 2014. The findings unveiled a substantial and unconditional impact of FD in reducing carbon emissions within the studied region. However, Acheampong (2019) Provided a more intricate perspective on the region using a similar methodology. Their study, which encompassed the period from 2000 to 2015, yielded mixed findings. While certain aspects indicated positive impacts of FD on carbon emissions reduction, others demonstrated a decrease in emissions. Additionally, specific financial indicators did not have a significant influence.

Moreover, the study's findings did not lend support to the presence of an EKC hypothesis in the region.

Tsaurai (2019) explored this relationship specifically within West African countries, employing pooled ordinary least squares (OLS), fixed effects, and random effects methods, with data spanning from 2003 to 2014. The author found that only domestic financial sector credit was linked to a substantial increase in carbon emissions within the region. Shahbaz et al. (2011) also found a negative long-term effect of FD on South Africa's carbon emissions from 1965 to 2008.

In general, it is evident that the issue of FD's impact on carbon emissions in Africa is complex and requires further study. Studies have yielded contradictory results, which may be attributable to the context, indicators, and country-specific characteristics. In the literature, the work of Acheampong (2019) shows a comprehensive approach, analyzing both the "direct and indirect" effects of FD on carbon emissions in SSA nations. However, this study has limitations, including its reliance on aggregated data and its focus on a specific region, which may not be applicable to another region.

2.2.3 Globalization and carbon emissions

Globalization is an intricate phenomenon involving the increasing interconnectedness and integration of economies, societies, cultures, and governments worldwide (Gygli et al., 2019). It encompasses multiple dimensions, including social, economic, and political factors. This process has paved the way for the unrestricted flow of goods, services, and information across international borders, as well as the widespread diffusion of technology and knowledge. Thus, it has spurred greater levels of innovation and contributed to economic growth (Gallagher, 2009; Zerrin and Yasemin, 2018). However, as economies grow and industries expand due to globalization, concerns have emerged about its effect on the environmental quality (Huo et al., 2022).

The discussion surrounding this issue revolves around two key theories: the "pollution halo" and the "pollution haven". The "pollution halo" hypothesis suggests that through globalization, international organizations can transfer greener technology and management practices to host countries (Gyamfi et al., 2022). This technology transfer includes eco-friendly remedies like pollution reduction and renewable energy technologies, which may effectively decrease carbon emissions. On the other hand, the "pollution haven hypothesis" presents a contrasting view. It suggests that

globalization may lead to a phenomenon where industries with high pollution levels relocate their operations to developing countries with less stringent environmental regulations (Bekun et al., 2023). The motivation behind this relocation is often driven by the desire to maintain competitiveness and reduce operational costs. However, the consequence of this movement can be detrimental to the environment in the host countries. These nations, with weaker ecological laws and enforcement mechanisms, may experience environmental degradation and an increase in carbon emissions (Zhang and Wang, 2021).

Empirical studies examining the relationship between globalization and carbon emissions have also significantly drawn upon these hypotheses, but they have produced divergent and conflicting results. For instance, Mehmood and Tariq (2020) focused on South Asian countries and examined this relationship spanning from 1972 to 2013. Employing advanced techniques such as the Autoregressive Distributed Lag (ARDL) and the Unrestricted Error Correction Model (UECM), the authors found that Afghanistan, Bangladesh, Nepal, and Sri Lanka exhibited a U-shaped relationship. However, in Bhutan and Pakistan, the association took on an inverted U-shaped pattern. Similarly, Liu et al. (2020) utilized a semi-parametric panel model spanning 1970 to 2015 to explore the relationship among G-7 countries and identified a U-shaped pattern. On a broader scale, Bu et al. (2016) embarked on an investigation encompassing 166 countries from 1990 to 2009, deploying the KOF globalization index. Their results indicated that carbon emissions tended to rise with higher levels of social, economic, and political globalization in non-OECD member countries, while the impact was found to be insignificant for member countries.

In contrast, You and Lv (2018) investigated utilizing a spatial panel model, encompassing data from 1985 to 2013, to assess the repercussions of economic globalization on carbon emissions across 83 countries. Their research brought to light the adverse impact of economic globalization on carbon emissions, accompanied by the revelation of emissions' spillover effects on neighboring nations. In a parallel vein, Audi and Ali (2018) examined this relationship within the MENA region, employing the panel ARDL approach spanning from 1980 to 2013. Their findings yielded a divergent perspective, indicating that globalization had a positive influence on environmental quality by curbing carbon emissions in the region. Shifting the focus to BRICS countries, Haseeb et al. (2018) further delved into this nexus, employing

dynamic, seemingly unrelated regression and the Dumitrescu-Hurlin causality technique, covering the years from 1995 to 2014. Their findings indicated that globalization had an insignificant effect on the region.

In the African context, Shahbaz et al. (2016) employed the ARDL and PMG techniques to investigate this relationship. Their findings indicated that globalization reduces the concentration of carbon emissions across the continent, albeit with varying outcomes among individual nations. Acheampong et al. (2019) examined this association in 46 sub-Saharan African (SSA) countries between 1980 and 2015, using trade openness as a proxy for globalization. Their analysis led to the conclusion that globalization significantly reduces carbon emissions in the region. In contrast, Kwabena et al. (2017) concluded that globalization contributes to an overall decline in the environmental quality of SSA countries, highlighting the complex nature of the globalization-environment relationship in Africa.

2.2.4 Comment and research gap

A comprehensive review of the existing literature above reveals several key insights and research gaps. Theoretical studies indicate that these factors can have both positive and negative effects on carbon emissions, with the overall impact depending on the magnitude of these effects. However, empirical research shows that the relationship varies depending on factors such as the sample, period, variables, and estimation methods used. However, significant limitations persist in current literature. Firstly, most studies focus on specific regions or countries, neglecting an African perspective. Secondly, the environmental impacts of globalization and financial development, which may be nonlinear or asymmetric, are often overlooked, potentially biasing results. Thirdly, limited scientific evidence substantiates how globalization and financial development can moderate economic growth while reducing carbon emissions. Finally, different methods, samples, and data have made it hard to compare the research of various scholars. Therefore, by addressing these research gaps in this study, a more comprehensive understanding of these relationships may be reached, which will benefit the aims of sustainable development and provide direction to academics and policymakers.

2.3 Methodology

2.3.1 Model

This study adopts Grossman and Krueger (1991) framework to explore the link between economic growth and carbon emissions. Initially, emissions rise with economic growth and energy consumption but eventually decline after an income threshold is reached. Nevertheless, this relationship is also influenced by other significant factors, such as financial development and globalization. FD can either increase emissions by promoting energy-intensive consumption or reduce them by facilitating investments in cleaner technologies (Zafar et al., 2019; Y. J. Zhang, 2011).

Globalization also notably affects carbon emissions (Le and Ozturk, 2020; Mehmood and Tariq, 2020). On one hand, globalization can stimulate emissions through foreign investments and trade (Tiba and Belaid, 2020). On the other hand, it can lead to cleaner technology transfer, resulting in more efficient production processes and lower emissions (Zafar et al., 2019). Additionally, globalization allows countries to specialize in eco-friendly products using environmentally friendly technologies, further reducing emissions (Shahbaz, Mallick, et al., 2015). Therefore, we extend the Grossman and Krueger (1991) model by incorporating financial development and globalization variables into the carbon emissions function as follows:

$$CO_2 = f(ECO, ECO^2, EC, FD, GLOB) \quad (2.1)$$

Where, CO_2 represent carbon emission; ECO is economic growth; EC indicates energy consumption; FD shows financial development; GLOB stands for globalization.

To mitigate potential issues stemming from heteroskedasticity and multicollinearity, the study employed a natural logarithmic transformation for all variables, thereby enhancing the robustness and precision of the results (Le and Ozturk, 2020). It also applied a dynamic reduced-form modeling approach inspired by Acheampong (2019), to examine the linear and nonlinear effects of globalization and FD on carbon emissions. The empirical equation is as follows:

$$\begin{aligned} \ln CO_{2i,t} = & \beta_1 \ln CO_{2i,t-1} + \beta_2 \ln ECO_{i,t} + \beta_3 \ln ECO_{i,t}^2 + \beta_4 \ln X_{i,t} \\ & + \beta_5 \ln FD_{i,t} + \beta_6 \ln FD_{i,t}^2 + \beta_7 \ln GLOB_{i,t} + \beta_8 \ln GLOB_{i,t}^2 \\ & + v_i + \varepsilon_{i,t-1} \end{aligned} \quad (2.2)$$

Where $\beta_1 \dots \beta_8$ represents coefficient values, and as v_i and $\varepsilon_{i,t-1}$ represent the intercepts of the time effect and lagged value of CO₂ emission, respectively, that vary across country- i at time t .

To investigate the moderating effect, we follow Acheampong (2019) work and adjust equation (1.2) by incorporating the interaction of “financial development and economic growth” ($\ln FD_{i,t} \times \ln ECO_{i,t}$), and globalization and economic growth ($\ln GLOB_{i,t} \times \ln ECO_{i,t}$). Thus, the final estimation of this model is defined as:

$$\begin{aligned} \ln CO_{2i,t} = & \beta_1 \ln CO_{2i,t-1} + \beta_2 \ln ECO_{i,t} + \beta_3 \ln ECO_t^2 + \beta_4 \ln X_{i,t} \\ & + \beta_5 \ln FD_{i,t} + \beta_6 \ln FD_t^2 + \beta_7 \ln GLOB_{i,t} + \beta_8 \ln GLOB_t^2 \\ & + \beta_9 (\ln FD_{i,t} \times \ln ECO_{i,t}) + \beta_{10} (\ln GLOB_{i,t} \times \ln ECO_{i,t}) \\ & + v_i + \varepsilon_{i,t-1} \end{aligned} \quad (2.3)$$

Where i represents individual units ranging from 1 to 52, t represents periods ranging from 1997 to 2021, X denotes a set of control variables, v signifies the individual effects, and ε represents the stochastic error term.

2.3.2 Data

The study utilizes data from 52 African nations, as detailed in Appendix 1.A, spanning the time frame of 1997 to 2021. The selection of countries and time were guided by data availability. The study measures carbon emissions in killo tone (kt), economic growth (real GDP per capita growth rate), energy consumption (kg of oil equivalent per capita), and population size (total population), all sourced from WDI (2021). Globalization is assessed using the KOF Globalization Index, considering “economic, social, and political dimensions” (Gygli et al.,2019). Each dimension is rated on a scale of 1 to 100, with higher values indicating greater globalization. The economic dimension includes trade openness, foreign direct investment, and economic integration. The social dimension covers interpersonal interactions, access to information, and cultural exchange. The political dimension examines political connections, international organization membership, treaty participation, and embassy numbers. Financial development is evaluated using the IMF's Financial Development

Index, incorporating financial institutions and markets ranging from the minimum value of 0 to maximum value of 1 (Svirydzenka, 2016). FI comprises banks, insurance companies, mutual funds, and pension funds, while FM encompass stock and bond markets. Table 2.1 provides a summary of the variables utilized in this study, along with their symbols, measurements, and data sources.

Table 2.1: Variables, symbols, measurements, and sources.

Symbol	Variable description	Measurement	Source
CO	CO ₂ Emission	Kiloton	WDI
ECO	Economic Growth	GDP per capita growth (%)	WDI
ENC	Energy Consumption	kg of oil equivalent per capita	WDI
POP	Population Growth	Total population (in millions)	WDI
FD	Financial Development	(0= Lowest,1= Highest)	IMF
FM	Financial Market	(0= Lowest,1= Highest)	IMF
FM	Financial Institution	(0= Lowest,1= Highest)	IMF
GLOB	Overall globalization	(1= Lowest,100= Highest)	KOF
ECONGLOB	Economic globalization	(1= Lowest, 100=Highest)	KOF
POLGLOB	Political globalization	(1= Lowest, 100=Highest)	KOF
SOCGLOB	Social globalization	(1= Lowest, 100=Highest)	KOF

2.3.3 Estimation technique

Panel data estimation is appropriate for this analysis because it can efficiently utilize both cross-sectional and time-series variations, resulting in more precise estimates (Arellano and Honoré, 2001). The panel provides a more accurate analysis by controlling unobserved heterogeneity specific to each unit. Panel data models also capture dynamic relationships over time, effectively address endogeneity concerns, offer increased degrees of freedom, and allow for testing heterogeneity and interactions (Yameogo et al., 2021).

The study also avoids using pooled OLS, fixed effect models (FE), and random effect models (RE) as estimation techniques. This decision stems from the limitations of these models in effectively addressing endogeneity issues that arise from the correlation between regressors and the error term in panel data analysis (Amuakwa-

Mensah and Adom, 2017). Pooled OLS, FE, and RE models may also be prone to omitted variables bias and have difficulty in accurately estimating the effects of time-invariant variables or unobserved individual-specific effects. The explanatory variables may also suffer from possible endogeneity in these models (M. Abid, 2017; Judson and Owen, 1999).

In panel data analysis, the "Generalised Method of Moments (GMM)" estimators are frequently utilized to surmount these limitations (Arellano and Honoré, 2001; Blundell and Bond, 1998). GMM estimators employ "instrumental variables" that are correlated with the regressors but uncorrelated with the error term, effectively controlling for endogeneity and producing consistent estimates. Incorporating lagged dependent variables as an internal instrument, GMM also captures dynamic relationships in panel data (Roodman, 2009). This enables the model to account for the persistence and time-varying character of the investigated variables, thereby increasing the precision of estimates. Moreover, GMM estimators are practical and resistant to the overidentification of instruments. They utilize the orthogonality conditions between instruments and the error term to achieve consistent and efficient estimates. This helps mitigate the problem of biased and inconsistent results that can arise from endogeneity in the data. Additionally, GMM can account for heteroscedasticity, which is the presence of different variances across observations. By incorporating weighting schemes or transformation techniques, GMM estimators can provide reliable estimates even in heteroscedasticity.

The difference GMM developed by Arellano and Bond (1991) estimator has the advantage of controlling endogeneity issues using "lagged differences of the dependent variable as instruments". It also eliminates fixed effects and captures the dynamics of the variables in dynamic panel data models. However, the difference technique assumes strict exogeneity, and the number of periods (T) is sufficiently large relative to the number of individuals (N) (Blundell and Bond, 1998). When the number of periods is limited, the instrument set used in the estimator may become weak or invalid. The GMM estimator relies on valid instruments to control endogeneity. Instruments are often constructed from lagged variable differences in dynamic panel data models. With a small T relative to N, there may need to be more variation in the lagged differences to construct valid instruments. As a result, the GMM estimator's ability to control endogeneity may need to be improved, leading to biased and

inconsistent parameter estimates. The System-GMM, a more advanced version of the “Difference GMM” developed by Blundell and Bond (1998), combines first-differences and “lagged levels of dependent variables as instruments” to address endogeneity in panel data analysis. It offers several advantages over Difference GMM, including more efficient parameter estimates, improved model accuracy by capturing both short-term dynamics (via first differences) and long-term relationships (via lagged levels), and better control of endogeneity by using a more extensive set of instruments (Wooldridge, 2003). Also, system GMM is particularly useful when dealing with panels of $T < N$.

Therefore, the application of System GMM in our study is justified for several reasons. Firstly, the panel consists of more countries ($N = 52$) than periods ($T = 25$ years). Second, GMM addresses the issue of cross-country disparity by incorporating cross-sectional dependence into the analysis, thereby assuring a thorough comprehension of the dynamics across countries. Finally, it provides a robust estimate that overcomes the issues of instrumental overidentification and heteroscedasticity, thereby improving the result's reliability and validity. (Yameogo et al., 2021).

In this study, the two-stage system GMM estimation method was preferred to the one-stage system GMM because it addresses potential problems related to missing values and improves control over endogeneity and serial correlation. Two-stage GMM also ensures a larger sample size, allowing for more reliable estimates and higher precision in panel data analysis (Roodman, 2009). By using different sets of instruments in the first and second steps, the two-step system GMM effectively deals with endogeneity problems. It takes into account the dynamic nature of the data.

The validation of the GMM model used in this study involved thoroughly assessing the identification and exclusion restrictions. These restrictions are critical since they guarantee that the model is correctly identified and that valid estimates are provided. The Hansen statistic was used to assess instrument validity, with a p-value greater than 5% indicating statistical significance. The Hansen test is preferred over the Sargan test for instrument validation because it can withstand heteroscedasticity and autocorrelation, as emphasized by Roodman (2009). Additionally, the study conducted autocorrelation tests for second-order errors, evaluated the joint significance of weak instruments, and examined the stationarity of the residual term in the regression

analysis. These rigorous validation procedures further enhance the robustness and reliability of the GMM model.

2.4 Empirical Results and Interpretation

2.4.1 Descriptive statistics

Table 2.2 presents the descriptive statistics for the variables under consideration. Carbon emissions (lnCO) displays a mean of 8% with a standard deviation (SD) of 1.9%. Additionally, the coefficient of variation (CV) is approximately 23.4%, exceeding the mean value. This suggests that carbon emissions in Africa exhibit instability throughout the analysis.

Table 2.2: Descriptive statistics.

Variable	Count	CV	Mean	SD	Min	Max
LnCO	1150	23.677	7.975606	1.889872	2.302585	13.12857
lnECO ₂	1259	151.074	1.537219	2.322246	-10.82835	9.888521
ECO	1259	412.391	1.718611	7.089718	-50.73415	140.367
lnPOP	1290	10.182	15.8317	1.611926	11.2557	19.16927
lnENC	555	13.257	6.261166	.8306944	2.260188	8.117767
lnGLOB	1057	5.206	3.861354	.2012985	3.198673	4.285791
lnFD	1224	172.892	-2.167972	.6394721	-5.702036	-.4421569
lnFM	1034	155.714	-4.494749	3.252162	-24.52688	-.5390081
lnFI	1224	58.447	-1.662515	.5382416	-5.423772	-.312849
LnECONGLOB	1057	6.466	3.789645	.2467116	3.175133	4.444884
lnPOLGLOB	1057	8.414	4.017345	.337863	2.744061	4.523417
lnSOGLOB	1057	9.222	3.665907	.3385742	2.386926	4.37475

The SD for the real GDP growth rate (ECO), the logarithm of financial development (lnFD), financial market (lnFM), and financial institutions (lnFI) are significantly greater than their respective averages. Also, Africa shows considerable variation in the real GDP growth rate and all financial development indicators, with CVs of 412.4%, 172.2%, 155.75%, and 58.4%, respectively. The logarithm of population growth (lnPOP) shows an average increase of 15.8% and 10.2% CV. Energy consumption (lnENC) in Africa shows volatility with a CV and mean of about 13.4% and 6.3%,

respectively. The logarithm of globalization (lnGLOB) has a mean value of 3.9% and a coefficient of variation of about 5.2%. In addition, the log values of economic (lnECONGLOB), political (lnPOLGLOB), and social globalization (lnSOGLOB) in Africa have mean values of 3.8%, 4%, and 3.7%, respectively, with coefficients of variation of 6.5%, 8.4%, and 9.2%.

2.4.2 Correlation matrix

Table 2.3 displays the correlation matrix between carbon emissions and independent variables along with their significance levels. To detect multicollinearity issues, a correlation coefficient below 0.85 is generally acceptable (Jiang and Ma, 2019). Therefore, it appears that the model is free from multicollinearity problems. Additionally, all independent variables, except for ECO, lnECO₂, and lnFI, exhibit positive correlations with carbon emissions. Also, the bivariate regression analysis depicted in (Figure 2.2) reveals a positive correlation between carbon emissions and the primary study variables. It indicates that as carbon emissions increase, there is a tendency for economic growth, FD and global factors to rise as well, suggesting a significant relationship between carbon emission and interested variables in the African context.

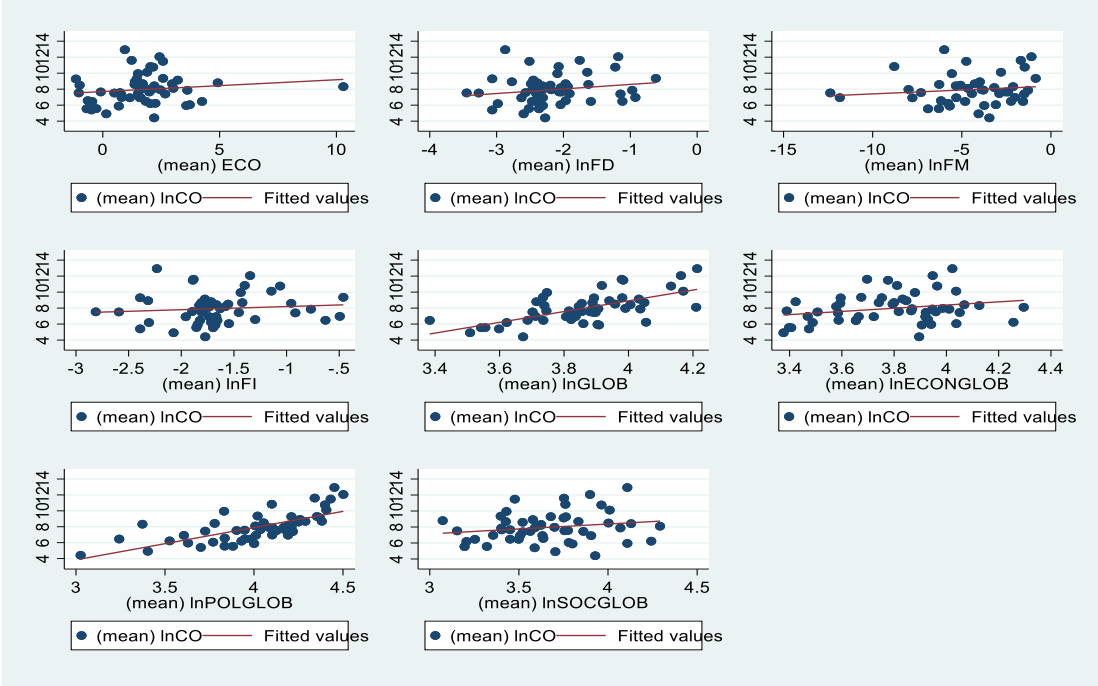


Figure 2.2: Bivariate regression analysis.

Table 2.3: Correlation matrix.

Variable	lnCO	LnECO ₂	ECO	lnPOP	lnENC	lnGLOB	LnFD	lnFM	lnFI	lnECONG LOB	lnPOLGLO B	lnSOGLOB
lnCO	1											
LnECO ₂	-0.0319	1										
ECO	0.0632	0.346***	1									
lnPOP	0.704***	-0.106*	0.00480	1								
lnENC	0.571***	0.119*	0.0651	0.0481	1							
lnGLOB	0.593***	0.0432	0.0656	0.203***	0.558***	1						
lnFD	0.177***	0.0452	0.0449	0.356***	-0.160**	0.0114	1					
lnFM	0.156**	-0.0761	0.0160	0.274***	-0.216***	0.0394	0.617***	1				
lnFI	0.0171	0.0866	0.0313	0.234***	-0.177***	-0.0575	0.917***	0.409***	1			
lnECONG LOB	0.172***	0.228***	0.118*	-0.210***	0.385***	0.632***	-0.228***	-0.105*	-0.254***	1		
lnPOLGLO B	0.700***	-0.0862	-0.0113	0.729***	0.326***	0.683***	0.267***	0.183***	0.175***	0.0245	1	
lnSOGLOB	0.209***	0.0366	0.0494	-0.356***	0.453***	0.740***	-0.148**	-0.0930	-0.151**	0.564***	0.121*	1

***, **, * explains the level of significance at 1%, 5% and 10%, respectively

The analysis of the CV, correlation, and bivariate regression highlights a strong and interconnected relationship among FD and globalization indicators and carbon emissions. Therefore, it is essential to consider multiple indicators of globalization and financial development rather than relying solely on one indicator for better understanding.

2.4.3 Effects of globalization on carbon emission in Africa

Following the estimation technique described in the methodology section, to address endogeneity issues and omitted variables in the analysis, a systematic approach was adopted. First, we performed Ordinary Least Squares (OLS) regression to explore the baseline relationships between economic growth, financial development, globalization, and carbon emissions. This provided initial insights into the variables' interdependencies. We then tested for endogeneity using the Durbin-Wu-Hausman test through a three-step process. First, we regressed each independent variable on all other independent and control variables to predict residuals, helping identify whether the variables were endogenous (correlated with the error term) or exogenous (uncorrelated with the error term). Next, residuals for each explanatory variable were calculated and included in the baseline OLS model to test their significance. The results confirmed endogeneity in at least one variable, requiring a more advanced estimation technique. To address this, we then estimated and compared fixed-effects and random-effects models, selecting the fixed-effects model¹ based on the Hausman test, which showed its superiority in controlling unobservable heterogeneity.

Recognizing the fixed-effects model's limitations in addressing endogeneity and dynamic relationships, we employed a two-step system Generalized Method of Moments (GMM) estimation. This approach incorporated lagged variables as instruments to address endogeneity, capture dynamic relationships, and account for omitted variables. To validate the instruments used in the GMM model, we performed the Hansen test, which confirmed their robustness, with all models yielding p-values exceeding 0.05. Furthermore, misspecification tests indicated significant first-order

¹ Prior to conducting the system-GMM analysis, the baseline results were estimated using a fixed effect estimator. However, due to space constraints, the outcomes of the fixed-effect estimator are not presented in this section. For detailed fixed effect results, please refer appendix A2.2.

autocorrelation (AR (1)) in the residuals ($p < 0.05$) but no higher-order autocorrelation, as evidenced by insignificant AR (2) residuals ($p > 0.05$). Residual stationarity was then confirmed using the Augmented Dickey-Fuller (ADF) test, further validating the model's suitability and goodness of fit. Finally, a joint F-test was conducted to assess the overall significance of the regression model. The highly significant results ($p < 0.01$) demonstrated the model's effectiveness in capturing the relationships between the variables. This comprehensive and rigorous approach confirmed the appropriateness of the two-step system GMM method for our analysis.

In Table 2.4, model I presents GMM result, wherein globalization indicators are excluded. Conversely, models II-V and VI-IX incorporate linear and nonlinear effects of globalization indicators, respectively. Across all models, the coefficient associated with lagged carbon emissions ($\ln CO$) consistently proves a significantly positive value at 1%. The coefficient values range from 0.564 to 0.896, showing a substantial impact of the previous year's carbon emissions on the emissions of the current year. This finding is in line with the conclusion of Acheampong et al. (2019) and Hao et al. (2016). Both studies identified a positive and substantial correlation between past emissions and those of the present. This is probably related to delayed policy effects and technological inertia from prior high-carbon infrastructure. Economic structures such as production processes, investment cycles, and supply chain dynamics may also contribute to sustained emissions from previous years, influencing current emissions patterns.

In all models, economic growth (ECO) consistently shows significant positive effect, ranging from 0.004 to 0.006 on emission. This suggests that Africa's growing economy drives up energy demand, mainly from carbon-intensive fossil fuels. Africa also has low energy efficiency, leading to higher emissions per unit of output. Increased traditional manufacturing processes with high energy use further elevate carbon emissions. This finding aligns with Onofrei et al. (2022) and Osadime and University (2021) but contrasts with Liu et al. (2022).

Also, the coefficient of squared Economic growth ($\ln ECO^2$) significantly negatively affects carbon emissions in most models, suggesting the presence of an EKC hypothesis in Africa. Interestingly, this study's findings contradict the inferences made by Acheampong (2019) and Abid (2016) concerning Sub-Saharan Africa (SSA). Our

finding claims that African economies initially worsen environmental degradation due to factors related to poverty, rapid population growth, urbanization, weak governance, resource-intensive practices, and limited technology. However, as economies grow and diversify, environmental awareness increases, and stricter regulations, greener technologies, and sustainable practices are adopted. This leads to a decoupling of economic growth and, thereby, carbon reduction.

This study also found that population size (lnPOP) in Africa is positively associated with carbon emissions, with a 1% increase in population linked to a 0.075% to 0.306% increase in carbon emissions. This is likely due to a combination of factors, including excessive consumerism, inadequate human capital development, and poverty. Additionally, population expansion leads to higher demand for energy, including fossil fuels, which also contributes to carbon emissions. Our findings corroborate with previous research by Acheampong (2022), Aye and Edoja (2017), and Dong et al.(2018), which emphasizes the relationship between population size and increased carbon emissions, likely driven by heightened fuel consumption and resource utilization.

Energy consumption (lnENC) is a statistically significant positive driver of carbon emissions in Africa in most models. A 1% increase in energy consumption increases carbon emissions by 0.089% to 0.514%. This is due to the heavy reliance on traditional nonrenewable energy sources, such as coal and oil, which release significant quantities of carbon dioxide when burned. The limited availability of cleaner and more sustainable energy alternatives exacerbates this dependence on carbon-intensive sources, amplifying the overall impact on carbon emissions in the region. Our findings line up Sahoo and Sahoo (2022) and Sarkodie et al. (2019) that have shown that energy use and carbon emissions tend to go hand in hand.

Table 2.4: Linear and nonlinear impact of globalization and its sub-indices on carbon emissions in Africa.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII	Model VIII	Model IX
L.lnCO	0.564*** (0.088)	0.896*** (0.045)	0.778*** (0.066)	0.804*** (0.059)	0.800*** (0.049)	0.764*** (0.056)	0.821*** (0.043)	0.626*** (0.134)	0.802*** (0.047)
lnECO ₂	-0.012 (0.008)	-0.007** (0.003)	-0.015*** (0.005)	-0.010* (0.005)	-0.007 (0.004)	-0.009* (0.005)	-0.012*** (0.004)	-0.009 (0.007)	-0.005 (0.003)
ECO	0.005* (0.003)	0.004*** (0.001)	0.005*** (0.002)	0.006** (0.002)	0.005*** (0.002)	0.004*** (0.001)	0.004*** (0.001)	0.006* (0.003)	0.004*** (0.001)
LnPOP	0.306*** (0.081)	0.075** (0.029)	0.177*** (0.052)	0.104** (0.050)	0.183*** (0.043)	0.164*** (0.048)	0.126*** (0.042)	0.188* (0.095)	0.171*** (0.043)
LnENC	0.514*** (0.168)	0.089* (0.049)	0.210* (0.104)	0.198 (0.123)	0.165** (0.068)	0.207** (0.091)	0.142** (0.052)	0.372** (0.183)	0.194** (0.073)
LnFD	0.125 (0.102)	0.043** (0.017)	0.089 (0.053)	0.092** (0.043)	0.066** (0.031)	0.073* (0.037)	0.092** (0.036)	0.128* (0.064)	0.061** (0.029)
lnGLOB		0.291** (0.136)							
LnECONG LOB			0.429** (0.200)				12.462** (4.603)		
lnPOLGLO B				0.228** (0.104)				-7.632 (4.714)	
lnSOGLOB					0.358*** (0.093)				3.126** (1.511)

Table 2.4 (continued): Linear and nonlinear impact of globalization and its sub-indices on carbon emissions in Africa.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII	Model VIII	Model IX
lnGLOB2						0.079*** (0.026)			
lnECONGLOB2							-1.589** (0.618)		
lnPOLGLOB2								1.055* (0.621)	
lnSOGLOB2									-0.397* (0.208)
Constant	-4.010** (1.631)	-1.860** (0.797)	-3.623*** (1.256)	-1.878* (1.038)	-3.388*** (0.883)	-2.887*** (0.872)	-25.427*** (8.393)	11.654 (9.452)	-8.133** (3.099)
Observations	504	460	460	460	460	437	437	460	460
AR (1)	0.007	0.003	0.005	0.005	0.004	0.005	0.008	0.010	0.004
AR (2)	0.152	0.124	0.131	0.130	0.133	0.135	0.179	0.176	0.133
Hansen	27.843	28.901	32.507	32.364	33.143	31.566	27.336	30.607	31.635
P(Hansen)	0.677	0.574	0.442	0.449	0.411	0.488	0.655	0.486	0.485
ADF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-statics	6508.105	119307.853	15641.764	17741.335	51246.754	19241.081	20944.884	8653.564	28525.513

***, **, * explains the level of significance at 1%, 5% and 10%, respectively

Regarding the impact of globalization, Model II reveals a significant positive association between overall globalization (lnGLOB) and carbon emissions. This aligns with Jahanger (2022) 's findings, indicating that a 1% increase in globalization corresponds to a 0.291% rise in carbon emissions. Model III further supports this positive effect, specifically for economic globalization (lnECONGLOB), where carbon emissions increase by 0.429% for every 1% increase in economic globalization. Several factors contribute to this phenomenon, with one of the primary drivers being the relocation of polluting industries from developed to developing countries through foreign direct investment. Using outdated technologies, these industries often expand carbon-intensive sectors such as manufacturing and mining. Permissive environmental regulations in African countries often encourage this, leading to higher emissions in these areas. Additionally, the increase in international trade essential to economic globalization requires significant energy use in transportation, further increasing carbon emissions. Our study's results are in agreement with the findings of Xu et al. (2018) but differ from those reported by Shahbaz et al.(2015).

Furthermore, the results from Model IV demonstrate that a 1% increase in the coefficient of political globalization (lnPOLGLOB) corresponds to a substantial 0.228% rise in carbon emissions. Our results align with the findings of Acheampong (2022). Political globalization is primarily measured through government policies. Throughout much of Africa, the absence of effective environmental policy has become a focal concern, intensifying carbon emissions. This regulatory framework deficiency, misaligned incentives, and insufficient emphasis on green technologies contribute to environmental degradation and heightened emissions. Furthermore, Africa has introduced many environmental policies to reduce carbon emissions, but these policies have not been effective due to limited public awareness and inadequate penalties for non-compliance.

In Model V, social globalization (lnSOGLOB) is shown to significantly impact Africa's carbon emissions, with a 1% increase correlating with a substantial 0.358% emissions rise. These results are further reinforced by the work of Jahanger (2022) and support the theory of ecological modernization, suggesting that global norms and cultural practices influence environmental policies and behaviors across nations. This may be related to African countries' environmental awareness and cultural exchange problems. Effective ecosystem management requires understanding human-nature

links, which cultural and ecological heritage can provide. However, due to globalization and large-scale migration, Africa faces several cultural problems, such as the loss of a country's native culture and values, a decreased desire for patriotism and nationalism, and a rise in the way of life that doesn't fit with local traditions, all of which contribute to carbon emissions.

Regarding the nonlinear effects, in Model VI, Model VII, and Model IX, overall globalization, economic globalization, and social globalization respectively show a decreasing impact on the rate of carbon emissions, while in Model VIII, political globalization demonstrates an increasing influence. Explicitly, a 1% surge in the square of overall globalization ($\ln\text{GLOB}^2$), economic globalization ($\ln\text{ECONGLOB}^2$), and social globalization ($\ln\text{SOGLOB}^2$) causes a respective decrease of 0.079%, 1.5%, and 0.4% in carbon emissions. However, a 1% rise in the square of political globalization ($\ln\text{POLGLOB}^2$) resulted a 10% rise in carbon emissions. These findings suggest that while overall, economic, and social globalization exhibit a concave, inverted U-shaped relationship with carbon emissions, political globalization displays a convex, U-shaped association in the context of Africa.

The existence of the ECK hypothesis in economic can be justified through the Pollution Haven Hypothesis. Initially, In the early stages of economic globalization, African nations may be more likely to attract polluting industries from developed countries. These countries may have weaker environmental regulations and lower labor costs. As a result, these countries may experience increased carbon emissions and environmental degradation. However, as economic globalization progresses, these countries may gain access to cleaner technologies and knowledge transfer, which can help reduce carbon emissions and improve environmental quality. Likewise, because of social globalization, carbon emissions in Africa might experience an initial spike due to heightened international travel, cultural exchange, and increased consumption.

However, this trend could gradually reverse over time, as promoting environmental awareness through social media leads to shifts in attitudes and behaviors, ultimately resulting in emission reductions. The exposure to worldwide environmental concerns, combined with the dissemination of sustainable practices through truism and culture exchange, further fosters the adoption of more eco-friendly lifestyles. The validity of

EKC hypothesis through economic and social globalization align with Liu et al. (2020) research on G7 countries.

Their study highlights globalization's role in fostering environmental consciousness and sustainable practices over time. However, political globalization, in its early stages, may drive African countries to adopt strict environmental regulations and emissions targets to secure aid, reducing emissions. Yet, over time, competition for economic growth through “race to the bottom” can relax regulations, increasing emissions as governments attract investment.

2.4.4 Effects of financial development on carbon emissions in Africa

Table 2.5 presents the impact of financial development, including its sub-indices, on carbon emissions in Africa. Model I has a notable positive relationship between overall financial development (lnFD) and carbon emissions, where a 1% increase in lnFD corresponds to a 0.026% increase in emissions. This finding is consistent with prior research in the field of developing countries (Hunjra et al., 2020; H. Khan et al., 2022), highlighting its robustness and alignment with existing conclusions. The positive association may be due to the lack of incentives that the financial system provides to firms for investing in green technologies or to consumers who prefer low-carbon emitting products (like electric cars). Furthermore, in developing countries like Africa, financial development mainly helps small and medium-sized businesses to grow. These businesses typically are on the increasing returns to scale output production level, and the more they grow, the more carbon emission they release.

Also, model II shows that the financial market (lnFM) has an insignificant impact on carbon emissions. This result contradicts the results of Paramati et al. (2018), who report that the financial market in the form of stocks has a positive and significant impact on carbon emissions. The coefficient of financial institutions (lnFI) in model IV shows statistically significant positive effects on carbon emissions at a level of 10%. Thus, a 1% increase in financial institutions leads to a 0.035% increase in carbon emissions. The observed outcome could be attributed to the challenges faced by African banks and insurance entities to promote the adoption of environmentally friendly technologies, enforce regulations for environmentally focused investments, and provide accessible project financing. These challenges impede investments in environmental sustainability, leading to increased carbon emissions.

Table 2.5: The linear and nonlinear impact of financial development and its sub-indices on carbon emissions in Africa.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
L.lnCO	0.950*** (0.018)	0.941*** (0.019)	0.862*** (0.063)	0.904*** (0.045)	0.899*** (0.070)	0.636*** (0.105)	0.721*** (0.069)
lnECO ₂	-0.003 (0.003)	-0.004 (0.002)	-0.008* (0.004)	-0.006* (0.003)	-0.008* (0.004)	-0.011 (0.009)	-0.014* (0.008)
ECO	0.004*** (0.001)	0.004*** (0.001)	0.005*** (0.001)	0.005*** (0.001)	0.005*** (0.002)	0.005** (0.002)	0.005** (0.002)
lnPOP	0.041*** (0.013)	0.045*** (0.013)	0.113** (0.050)	0.070** (0.030)	0.087* (0.045)	0.237** (0.097)	0.225*** (0.059)
lnENC	0.030* (0.018)	0.036 (0.022)	0.130* (0.076)	0.077 (0.056)	0.055 (0.093)	0.335** (0.157)	0.200* (0.107)
lnGLOB	0.148* (0.080)	0.154* (0.081)	0.282* (0.139)	0.303* (0.154)	0.285 (0.182)	0.701* (0.368)	0.711*** (0.259)
lnFD		0.026** (0.010)			0.499* (0.295)		
lnFD2					-0.123* (0.064)		
lnFM			0.008 (0.006)			0.147** (0.057)	
lnFI				0.035* (0.018)			1.151** (0.540)
lnFM ²						-0.006** (0.002)	
lnFI ²							-0.334** (0.154)
Constant	-0.952** (0.395)	-0.922** (0.403)	-2.442** (1.023)	-1.856** (0.896)	-2.391** (1.098)	-4.934** (1.839)	- 6.052*** (1.416)
Observations	422	410	378	460	460	378	460
AR (1)	0.002	0.003	0.014	0.003	0.006	0.023	0.009
AR (2)	0.245	0.123	0.118	0.127	0.158	0.131	0.308
Hansen	30.588	28.679	23.945	27.878	28.929	26.455	32.760

Table 2.5 (continued): The linear and nonlinear impact of financial development and its sub-indices on carbon emissions in Africa.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
P(Hansen)	0.436	0.535	0.813	0.627	0.521	0.699	0.381
ADF	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-statics	419107.5	234040.3	105474.4	121580.7	71818.3	8147.7	9265.1

***, **, * explains the level of significance at 1%, 5% and 10%, respectively

This finding contradicts the existing literature, including the study conducted by Habiba et al. (2021), which affirms that financial institutions exert an insignificant influence on carbon emissions within developing G20 countries.

Regarding the nonlinear effects, the outcomes observed in Models V, VI, and VII underscore a noteworthy trend. These results suggest that both overall financial development and its sub-indices play a significant role in reducing carbon emissions, aligning with the evidence of an inverted U-shaped relationship. These results contradict those of Acheampong (2019), who found that financial development indicators do not have a significant nonlinear effect on carbon emissions in SSA. The presence of an inverted U-shaped association implies that as FD advances beyond a certain point, it becomes increasingly effective in mitigating carbon emissions. This may be due to improved financial mechanisms facilitating investments in cleaner technologies or more efficient resource utilization, ultimately leading to reduced environmental pollution.

2.4.5 The moderating effect of globalisation and financial development on CO₂ emissions in Africa

In Table 2.6, Models I to III focus on illustrating how financial development and its sub-indices moderate carbon emissions. Also, Models IV to VII delve into the moderating effect of overall globalization and its sub-indices indicators on carbon emissions. Model 1 of Table 2.6 reveals that the interaction of FD and economic growth (lnFDECO) shows a significant and negative influence on carbon emissions, with a statistical significance level of 10%. This outcome implies that for every 1% increase in the coefficient of lnFDECO, there is an associated 0.022% decrease in carbon emissions. This implies that financial development can improve environmental quality by moderating economic growth. The inference is that financial development

encourages transferring traditional green supply chain management approaches and eco-friendly technologies to the African economy, thereby reducing carbon emissions. In addition, it delivers services with reduced investment costs by applying procedures and regulations that foster economic development and thus help to reduce carbon emissions. This finding is contradict with that of Wang et al. (2019) and align with those of Acheampong (2019).

However, the result from Model II indicates that the interaction effect of financial market and economic growth (lnFMECO) shows positive and insignificant. This may be because the financial sector in Africa does not efficiently allocate resources to environmentally sustainable sectors, thus contributing to increased carbon emissions. Nonetheless, financial development measured by financial institutions (lnFIECO) can effectively moderate economic growth and significantly decrease carbon emissions at a 10% significance level in Model III. This highlights the importance of developed financial institutions in channeling investments towards sustainable projects and promoting adopting green technologies to reduce carbon emissions.

Table 2.6: The moderate effect of globalisation and financial development on CO₂ emissions in Africa.

Variables	Model I	Model II	Model III	Model IIV	Model V	Model VI	Model VII
L.lnCO	0.687*** (0.087)	0.765*** (0.082)	0.620*** (0.128)	0.747*** (0.072)	0.779*** (0.061)	0.788*** (0.072)	0.787*** (0.056)
lnECO ₂	-0.010 (0.008)	-0.012** (0.006)	-0.019** (0.007)	-0.015** (0.007)	- 0.034*** (0.011)	-0.008 (0.007)	-0.009* (0.005)
ECO	-0.041 (0.025)	0.011** (0.004)	-0.030 (0.022)	0.085 (0.088)	0.416** (0.189)	0.133* (0.069)	0.072* (0.038)
lnPOP	0.192*** (0.069)	0.182** (0.072)	0.262*** (0.094)	0.164*** (0.051)	0.150*** (0.049)	0.120** (0.045)	0.193*** (0.053)
lneENC	0.223** (0.103)	0.183 (0.125)	0.306 (0.223)	0.156* (0.087)	0.119 (0.094)	0.183 (0.133)	0.133 (0.090)
lnGLOB	0.889*** (0.285)	0.542** (0.235)	1.010*** (0.306)	0.799*** (0.221)			
lnFD	0.157* (0.081)			0.061 (0.060)	0.078 (0.052)	0.058 (0.056)	0.053* (0.030)

Table 2.6 (continued): The moderate effect of globalisation and financial development on CO₂ emissions in Africa.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
lnFDECO	-0.022*						
	(0.012)						
lnFM		0.012					
		(0.012)					
lnFMECO		0.001					
		(0.000)					
lnFI			0.098				
			(0.077)				
lnFIECO			-0.023*				
			(0.014)				
lnGLOBECO				-0.020			
				(0.022)			
lnECONGLOB					-		
					0.872***		
					(0.309)		
lnECONECO					-0.104**		
					(0.048)		
lnPOLGLOB						-	
						0.356**	
						(0.140)	
lnPOLECO						-0.031*	
						(0.017)	
lnSOGLOB							-
							0.589***
							(0.135)

Table 2.6 (continued): The moderate effect of globalisation and financial development on CO₂ emissions in Africa.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
lnsSOECO							-0.017* (0.010)
Constant	-4.858*** (1.624)	-4.022*** (1.377)	-6.547*** (2.168)	-4.328*** (1.091)	-4.320*** (1.309)	-2.486** (1.035)	-4.143*** (1.090)
Observations	420	378	449	351	351	314	277
AR (1)	0.005	0.015	0.005	0.007	0.003	0.011	0.007
AR (2)	0.234	0.139	0.204	0.182	0.328	0.286	0.190
Hansen	28.258	24.100	27.503	26.556	27.969	29.173	25.378
P(Hansen)	0.346	0.841	0.491	0.433	0.360	0.214	0.279
ADF	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-statics	8029.06	16597.29	6557.30	10912.45	16520.44	12971.92	26295.71

***, **, * explains the level of significance at 1%, 5% and 10%, respectively

Similarly, the results derived from Model IIV indicate that the moderating effect of overall globalization (lnGLOBECO) negatively and insignificantly impacts carbon emission. However, Models V, VI and VII lend support to the idea that the moderating impact of economic globalization (lnECONECO), political, social globalization (lnPOLECO), and social globalization (lnsSOECO) significantly contribute to the mitigation of carbon emissions, with statistically significant effects at 10% and 5% levels respectively.

This result pioneering endeavor scrutinizing the interplay between globalization and economic growth in environmental dynamics. It offers a fresh perspective on environmental literature and opens new possibilities for utilizing globalization to drive long-term structural changes in economies. The rationale behind these findings may lie in the hypothesis that well-managed globalization can serve as a catalyst for various positive outcomes. These include the promotion of technological innovation, the elevation of environmental standards, the enhancement of overall productivity through increased trade activity, and the stimulation of economic growth via foreign direct investment and advanced transactions. This, in turn, enables nations to transition their economies into more sophisticated, knowledge-based manufacturing centers, resulting

in the production of goods with lower energy-intensive footprints. Embracing global openness emerges as a promising avenue for concurrently improving environmental quality while reaping the desired benefits of structural economic change.

2.5 Conclusion and Recommendation

This study examines the impact of globalization and financial development on carbon emissions in 52 African countries from 1997 to 2021. It assesses linear and non-linear effects while considering the moderating role of globalization and financial development in the relationship between economic growth and carbon emissions. Fixed effects and a two-step system-generalized method of moments are used for analysis.

The findings from this study are presented sequentially: Initially, economic growth leads to increased emissions due to energy-intensive activities, but there's potential for emissions to decline as economies advance, aligning with the EKC hypothesis. Population size and energy consumption are significant contributors to carbon emissions. While overall globalization and financial development linearly increase emissions, the squared values of economic and social globalization exhibit an inverted U-shaped relationship, suggesting the potential for globalization to promote sustainability. Financial development, when squared, negatively impacts emissions, aligning with the EKC hypothesis. Moreover, globalization and financial development play crucial roles in moderating the connection between economic growth and emissions, emphasizing the importance of targeted policies and sustainable practices in Africa's development journey. The study's key findings highlight the complex relationship between economic growth, globalization, financial development, and carbon emissions.

In light of the empirical findings, several policy implications are due. First, globalization and financial development have a significant linear impact on carbon emissions in Africa. These trends amplify the scale and intensity of economic activity, resulting in elevated levels of greenhouse gas emissions. To tackle this challenge, African countries need to adopt a multifaceted approach. To counteract the effects of economic globalization, policymakers should embrace a two-pronged strategy. They should incentivize the adoption of cleaner technologies and sustainable practices among industries. Policy makers should also institute stringent environmental

regulations to counteract the pollution haven effect. Strengthening domestic governance and fostering international collaborations are vital for managing the emissions impact of political globalization.

Promoting environmental education, community initiatives, and encouraging green consumer choices can mitigate the repercussions of social globalization. Financial development policies should concentrate on embedding sustainability within financial institutions. Pressing green investments and loans through targeted approaches and regulatory frameworks can advance environmentally friendly projects. Additionally, fostering renewable energy development using innovative financial mechanisms can assist in curtailing carbon emissions. Policymakers should prioritize promoting green financing mechanisms and sustainable investment options to mitigate the positive correlation between financial development and carbon emissions. This entails encouraging the adoption of eco-friendly technologies and enforcing regulations that guide financial institutions towards eco-conscious lending practices, thereby mitigating the carbon-intensive consumption patterns attributed to underregulated financial systems.

Secondly, the nonlinear effects of economic and social globalization, financial development, and sub-indices exhibit an inverted U-shaped correlation with emissions. Effective policy interventions must be tailored to facilitate the transition from the initial upward phase of this relationship to the subsequent downward trajectory. To this end, African nations should prioritize attracting investments and technologies that prioritize environmental sustainability during the initial stages of economic globalization. Collaborative efforts should focus on disseminating sustainable practices and technologies, capitalizing on the networks established during the phase of social globalization. Regarding the U-shaped relationship with political globalization, balanced policies are imperative. They should harmonize growth with steadfast environmental regulations, discouraging a "race to the bottom" through international agreements. Additionally, policymakers should foster the development of green financial instruments and enforce regulations that promote sustainable investment.

Thirdly, policymakers can harness globalization and financial development to reshape the interplay between economic growth and carbon emissions. Advanced and cleaner technologies can be propelled by strategically deploying fiscal incentives like tax

breaks and grants, in conjunction with emissions regulations. Simultaneously, sustainable supply chain management can be cultivated through mandatory emission reduction standards or voluntary agreements. This momentum towards sustainability gains further impetus by enforcing environmental limits through legislation. Enterprises integrating eco-friendly practices can benefit from incentive programs, while rigorous regulatory frameworks for financial institutions ensure responsible investment. Collaborative partnerships between these institutions and environmentally conscious businesses, supported by joint lending, investment, and research initiatives, expedite the transition towards a greener, more resilient economic future.





3. THE ROLE OF GREEN INNOVATION, RENEWABLE ENERGY, AND INSTITUTIONAL QUALITY IN ACHIEVING GREEN GROWTH IN AFRICA

3.1 Introduction

Following the dawn of industrialization in the mid-18th century, the global economy experienced remarkable growth and development (Liao et al., 2018). However, there is growing concern about the negative environmental impacts of this growth. Rapid growth requires high resource consumption that causes severe ecological damage, including pollution and climate change (Merko et al., 2019). In addition, environmental damage impedes the growth of the global economy, putting sustainable development at the top of the international agenda (Wada et al., 2021).

Various tools and programs have been introduced over the past few decades to reconcile high economic growth and environmental protection. In 2015, the United Nations (UN) launched the 2030 Agenda for Sustainable Development and introduced 17 Sustainable Development Goals (SDGs) to end poverty in all forms. In the same year, 196 countries signed the Paris Agreement, a legally binding international treaty on climate change whose main objective is to achieve zero emissions by 2050 and thereby limit the global average temperature to 2°C above preindustrial levels (UNFCCC, 2015).

However, the progress toward SDGs and the terms of the Paris Agreement is slow and uneven. Many countries still face severe poverty, income inequality, and environmental degradation. The main challenges preventing progress toward sustainable development are political hesitation, path dependency, and lack of cooperation among nations (Leal et al., 2020).

Green growth is a viable approach to achieving the coincident objectives of fostering economic growth and development while preserving the services of natural resources and the environment (OECD, 2020). Green growth strategies comprise integrating environmental concerns into economic decision-making processes and restructuring

industries to prioritize the environment, such as investing in clean technologies, renewable energy, and resource efficiency. While innovation in green technologies is deemed to stimulate efficiency gains, cleaner technologies and renewable energy use reckon with alleviating environmental damage (Ferreira et al., 2023; Ahmed et al., 2021; Syed & Tripathi, 2018).

On the back of this background, this study aims to identify the determinants of green growth. We hypothesize that green innovation, renewable energy consumption, and institutional quality are essential factors that promote green growth. Green innovation involves developing products, services, and processes that use natural resources efficiently without harming the environment. Hence, while low greenhouse gas emitting machinery, equipment, and processes help mitigate environmental damage, industries that adopt these innovations are transformed into sustainable growth paths (Chang, 2011; Rehman et al., 2021).

Augmenting renewable energy sources is also crucial in promoting green growth. Investing in renewable energy sources such as solar, wind, and hydropower can help reduce dependence on fossil fuels while satisfying electricity demand and increasing energy security for countries worldwide (Gorji & Martek, 2023). Additionally, it aligns with the principles of green innovation, as it promotes the efficient utilization of natural resources and promotes environmentally friendly technologies.

Institutional factors, such as political stability, the rule of law and democracy, and bureaucratic quality, lead to economic growth and improve environmental quality (Azam & Emirullah, 2014; Joshua et al., 2022; Salman et al., 2019). On the other hand, poor institutional quality can hinder entrepreneurship and innovation, leading to the persistence of low-income areas (Kar et al., 2019) and low environmental quality. Moreover, institutional quality also affects the environmental quality of surrounding nations through spatial diffusion channels (Hosseini & Kaneko, 2013). Thus, institutions may be pivotal in shaping societal rules, norms, and structures as crucial facilitators of green growth.

In investigating the effects of green innovation, renewable energy consumption, and institutional quality on green growth, this study focuses on African economies for several reasons. First, Africa is currently the second fastest-growing continent in the world. Between 2000 and 2021, its average annual growth rate was 4.1% (compared

to 3.06% of the world average growth rate), and it is expected to increase to nearly 5-6% in 2030 (African Development Bank, 2014). However, this rapid growth has come at a cost, leading to increased energy consumption, pollution, and environmental degradation (Acheampong et al., 2021; Shepard, 2019).

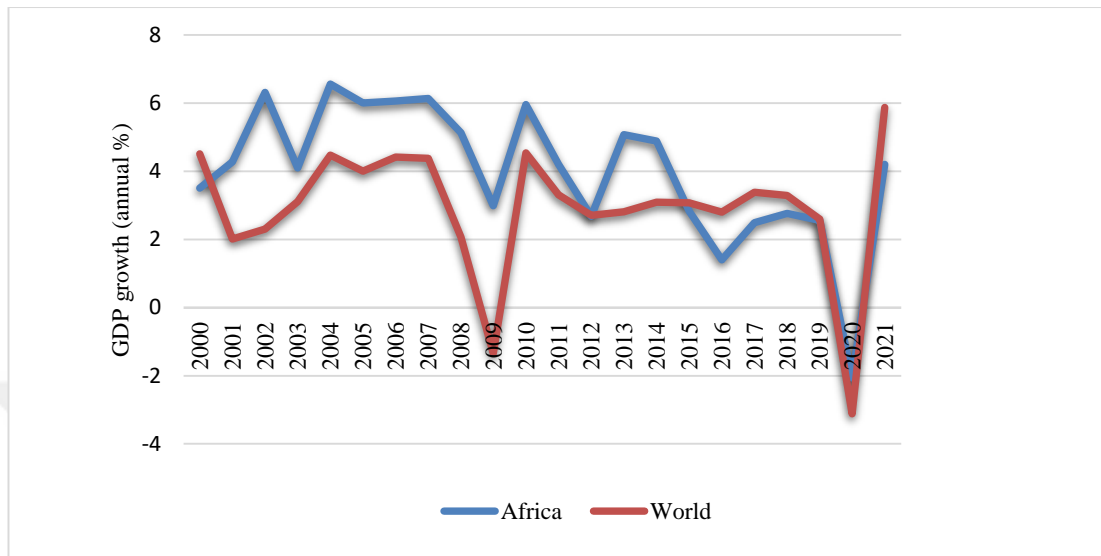


Figure 3.1: Africa's and world GDP growth rate from (2000 to 2021).

At the same time, poverty is widespread in Africa, and many people live below the poverty line. Therefore, restricting the current growth process to mitigate environmental degradation is not a viable option for policymakers in the continent. Alternative approaches, such as green growth strategies, become crucial to ensure that Africa's economic success is achieved in an environmentally responsible and socially inclusive manner.

Second, while contributing a relatively low share of global carbon emissions, estimated at 0.7-1.3 billion metric tons annually between 2000 and 2021 (see Figure 3.2), Africa bears a disproportionately heavy burden from the consequences of climate change. This disparity becomes evident when compared to major emitters like Asia-Pacific (7.7-17.7 billion), North America (6.6-5.7 billion), and Europe (4.8-3.8 billion). This unequal distribution of emissions transforms into tangible hardships for Africa, with approximately 250 million people already experiencing water stress and an estimated 80% of African countries projected to lack sustainable water management by 2030 (WMO, 2022). This situation underscores the urgent need for approaches that concurrently address environmental challenges and support sustainable economic growth.

Third, Africa’s commitment to achieving the SDGs by 2030 and the Paris Agreement by 2050 requires a shift to sustainable resource management that prioritizes conservation, biodiversity protection, and renewable energy consumption (Sperling et al., 2012). Therefore, identifying the determinants of green growth and making policy recommendations in this direction will promote sustainable development on the continent and help African policymakers move forward toward their commitment to the SDGs and the objectives of the Paris Agreement.

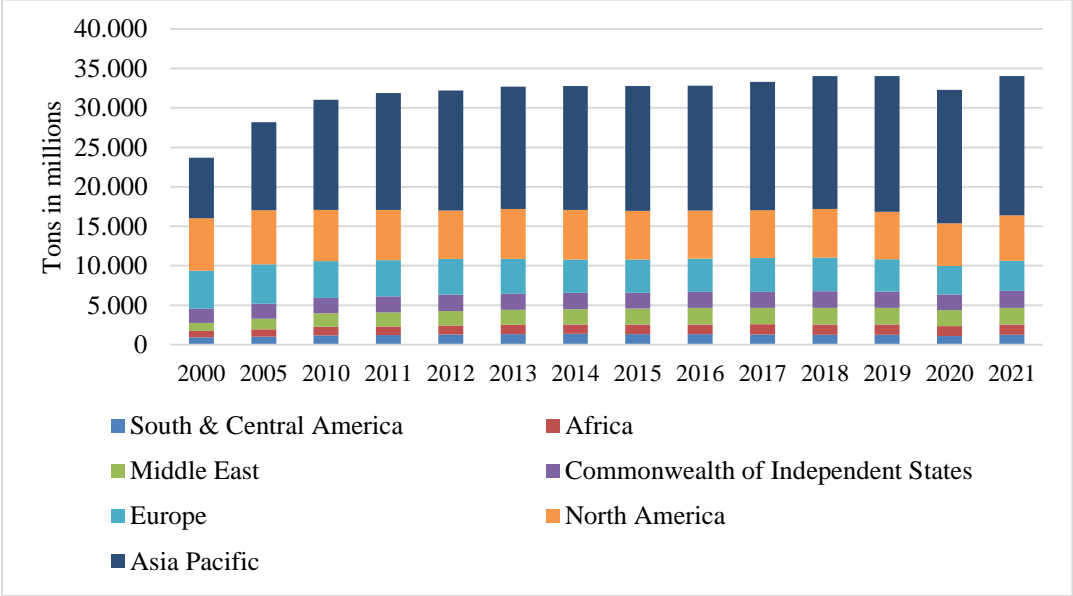


Figure 3.2: Africa's CO₂ emissions in millions of tons (2000 to 2021).

To our knowledge, this study is the first to empirically examine the role of institutional quality, green innovation, and renewable energy in Africa's green growth. The paper also strays from the typical carbon emissions approach in the environmental literature. It highlights the importance of green growth in the efficient use of natural resources, economic development, and ecological sustainability. To this end, this paper generates the green growth variable for 49 African countries by utilizing the conventional formula proposed by Vaghefi et al. (2015). The results indicate that green innovation, renewable energy consumption, and institutional quality have positive long-run effects on green growth, while in the short run, only institutional quality positively affects green growth.

3.2 Literature Review

3.2.1 Green innovation and green growth

Porter & Van Der Linde (1995) challenged the conventional view that there is a tradeoff between environmental protection and economic competitiveness. The authors argue that this approach assumes a static world where ecological regulations would increase firms' costs that already established their cost-minimizing production plans.

However, according to the authors, the new paradigm of international competitiveness is based on the firm's ability to improve and innovate continually. Hence, they argued that properly drafted and more stringent environmental regulations can stimulate innovation and enhance firms' competitiveness. In this vein of research, Acemoglu et al. (2016) developed an endogenous growth model where clean and dirty technologies compete in production and innovation. The authors show that while research may be directed to either type of technology, the more advanced the dirty technology, the more difficult it is to move toward clean technologies. Accordingly, the authors suggest that research subsidies toward clean technologies would be optimal for welfare improvements. The results of (D Acemoglu et al., 2016) also imply the importance of institutions in green growth both in the short and long run. As they would not allow the implementation of dirty technologies, stronger institutions would contribute to green growth both in the short and long run.

On the other hand, Chang et al. (2018) note that energy efficiency improvement may save less energy than expected due to rebound or backfire effects of energy use. The rebound effect refers to less than one-for-one energy correspondence between energy efficiency gains and reduced energy use. In contrast, backfire relates to cases where energy efficiency increase energy use. The authors develop a dynamic general equilibrium macroeconomic model to identify the macroeconomic effects of environmental rebound and backfire effects. They find that in terms of pollution, the macroeconomic rebound effect on the economy may be substantial in several situations, such as when the elasticity between clean and dirty energy consumption is lower or the environmental efficiency of clean energy is lower.

On the back of these competing theoretical predictions, several researchers have analyzed the relationship between green innovation and green growth. For instance,

Fernandes et al. (2021) assess the effect of green development on economic expansion using data from 32 OECD countries from 1990 to 2013. The authors find that sustainable technology transfer and innovation positively contribute to green growth and economic development. Specifically, the authors suggest that innovations and technology contribute to green growth by supporting environmentally friendly transportation, promoting clean consumption, and optimizing corporate supply chains.

Mohamed et al. (2022) investigate the impact of innovation on economic development in developing countries from 1990 to 2018. The authors find that increased technological innovation leads to short-term and long-term economic growth, and innovation is crucial in attaining sustainable development in developing countries.

Danish & Ulucak (2020) analyze the effect of green innovation on the green economy in the BRICS (Brazil, Russia, India, China, and South Africa) economies from 1992 to 2016. Their findings demonstrate that innovation in environmental technologies is crucial in promoting green growth. Chen et al. (2023) also investigate the effects of green innovation and financial globalization on green growth in the BRICS economies. Their findings also support the idea that green innovations are instrumental in attaining green growth.

While green innovation is usually found to contribute to economic development, the results may vary with the economic structure of the countries examined. In this regard, Danish & Ulucak (2021) find that while technological innovation reduces carbon emissions in the US, the effect is not statistically significant in China. Since such asymmetries may be present in low-income countries, in this paper, we take a holistic approach and study the positive and negative aspects of green innovation on green growth in the context of Africa.

3.2.2 Renewable energy and green growth

Transitioning to renewable energy sources is critical in mitigating climate change and fostering sustainable development. Unlike fossil fuels, which contribute significantly to greenhouse gas emissions, renewable sources such as solar, wind, and geothermal power offer clean and sustainable energy alternatives (Wei et al., 2023). Beyond their environmental benefits, renewable energy sources also hold the potential to stimulate economic growth because they are cost-effective, provide energy security, and help alleviate poverty by extending electricity to remote areas due to their decentralized

nature (Mahjabeen et al., 2020). In this regard, studies have extensively explored the relationship between renewable energy and sustainable development using various theoretical and empirical frameworks.

Theoretically, two prominent frameworks have been employed to analyze the nexus between renewable energy and economic growth: the environmental Kuznets curve (EKC) hypothesis and endogenous growth theory. The EKC hypothesis postulates an inverted U-shaped relationship between economic growth and ecological degradation (Grossman & Krueger, 1995). This implies that environmental degradation initially increases with economic growth, as economies prioritize rapid development and rely heavily on traditional energy sources with significant ecological consequences. However, as economies mature and reach a certain level of development, environmental awareness and technological advancements shift towards more sustainable practices, including adopting renewable energy sources. This transition contributes to a decline in environmental degradation, resulting in the descending part of the EKC curve.

In endogenous growth theory, technological development occurs either as a byproduct of the production process or as a consequence of intentional research and development activities (Romer, 1994). This theory implies that renewable energy can promote economic growth by enhancing the productivity and efficiency of the economy, as well as by creating new markets and opportunities for innovation (Wang & Wang, 2021).

Regarding the effects of renewable energy production on economic growth, the International Energy Agency (IEA) found that renewable energy could create 28 million new jobs worldwide by 2050 (IEA, 2021). Bhuiyan et al. (2022) surveyed the studies on renewable energy and economic growth, revealing a positive and significant relationship between the two variables in developing countries. Tawiah et al. (2021) identified a positive correlation between renewable energy consumption and resource efficiency across 123 industrialized and developing nations. Ahmed et al. (2021) showed that higher levels of renewable energy consumption were associated with increased economic growth rates in South Asian countries from 2000 to 2018.

While most studies support the positive contribution of renewable energy to green growth, a few present contrasting findings. Menegaki (2011) found no causal relationship between renewable energy consumption and economic growth in 27

European countries from 1997 to 2007. Venkatraja (2020) suggested that renewable energy may initially impede economic growth due to high capital investment and limited technological advancements, with this negative impact potentially diminishing as economies advance. Mehdi & Slim (2017) observed that increased use of combustible renewables in five North African nations between 1980 and 2011 led to higher carbon emissions, potentially hindering green growth. Similarly, Gasparatos et al. (2017) cautioned about potential environmental consequences of large-scale renewable energy adoption, including impacts on land use changes, resource extraction, and manufacturing waste. Thus, there is a need for further research to address remaining gaps and optimize the integration of renewable energy into global green growth agendas.

3.2.3 Institutional quality and green growth

Strong institutions enable the establishment of comprehensive environmental regulations and catalyze the widespread adoption of cleaner technologies, reducing pollution emissions and safeguarding natural resources (Daron Acemoglu & Robinson, 2010; Shahbaz et al., 2019). They promote sustainable resource management by delineating property rights and instituting governance frameworks that discourage overexploitation (Asoni, 2008; Mustapha et al., 2018). Moreover, institutions initiate innovation in green technologies by providing financial support, formulating supportive policies, and fostering collaboration between research institutions and businesses (Ying Li & Li, 2021).

A growing body of empirical research has delved into the influence of institutional quality on green growth progress. For instance, Tawiah et al. (2021) argued that institutional quality dimensions such as government effectiveness and the rule of law could promote environmental quality and green growth in developing countries. Ahmed et al. (2021) found that institutional quality and financial development were crucial drivers of long-term green economic growth in South Asian countries between 2000 and 2018. Similarly, Shahbaz et al. (2019) reveal that the quality of institutions plays a vital role in enhancing environmental quality through the effective implementation of economic and environmental policies, including the provision of supportive financial mechanisms. Similarly, Li & Li (2021) investigated the role of environmental regulation on total green factor productivity (GTFP) in China's

manufacturing industry from 2003 to 2016. The study constructs a comprehensive indicator of environmental regulation and calculates GTFP using the SBM directional distance function and the Malmquist–Luenberger productivity index. The authors find that environmental regulation has a positive effect on GTFP.

While there is growing evidence of the link between institutional quality and green growth, some studies have found that solid institutions may not always lead to positive outcomes. For instance, Obobisa et al. (2021) examine the impact of institutional quality on carbon emissions in 25 African countries from 2000 to 2018, and they find that institutional quality can positively impact carbon emissions. The authors conclude that the lack of stringent environmental regulations or the failure to enforce existing regulations may increase emissions. Fabrice et al. (2023) find mixed impact of institutional quality on green economic growth in West African Economic and Monetary Union (WAEMU) countries. Specifically, the study finds a positive effect of institutional quality on green economic growth in Côte d'Ivoire, Mali, Niger, Senegal, and Togo. However, the effect is negative in Benin and Burkina Faso. The authors suggest that WAEMU countries improve their institutional frameworks, mainly by eliminating corruption, improving government effectiveness, strengthening the credibility of government policies, and implementing sound environmental policies and regulations.

In summary, while evidence supports the link between institutions and green growth, further research is necessary to understand the specific mechanisms at play, the effects of different types of institutions and reforms, and the factors contributing to variations in institutional impact across countries and regions. Moreover, there is a need for focused empirical research on the relationship between institutional quality and green growth in African nations.

3.3 Methodology

3.3.1 Data

This paper examines 49 African countries² from 2000 to 2021, selected based on data availability. The study focuses on green growth as the dependent variable, which separates economic growth from resource consumption and environmental harm (Hussain et al., 2022; OECD, 2020). Due to data constraints in Africa, the paper constructs green growth data using the formula proposed by Vaghefi et al. (2015), which incorporates GDP, education expenditure, fossil fuel consumption, forest depletion, and carbon damage:

$$GG = GDP_t + EDU_t - NRD_t - NFD_t - CO_{2t} \quad (3.1)$$

Where GG represents green growth, GDP_t indicates gross domestic product, EDU_t indicates education expenses, NRD_t represents natural resource depletion for the depletion of minerals such as coal, crude oil, and natural gas, NFD_t denotes forest depletion, and CO_{2t} is carbon damage. The calculation of the monetary value of the carbon damage variable relies on the World Bank convention that employs a fixed unit damage cost of 40 USD per ton of carbon emitted in 2020, measured in 2017 US dollars. This unit cost is a standardized metric for the economic damage associated with each ton of carbon.

The independent variables include green innovation, renewable energy, and institutional quality green growth, alongside factors such as trade openness, foreign direct investment (FDI), economic growth, population, and natural resource rent. Data for GDP per capita, trade openness, FDI, renewable energy consumption, population, and natural resource rents are sourced from the World Development Indicators (WDI) database, while total patents from the OECD database serve as a proxy for green innovation.

² Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo Republic, Cote d'Ivoire, Congo Dem. Rep., Egypt, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, and Zimbabwe.

Institutional factors are assessed using the Worldwide Governance Indicators (WGI) developed by Kaufmann & Kraay (2020), which cover six dimensions of governance: voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, and control of corruption.

Table 3.1: PCA regression for the institutional quality variable.

Component	Eigenvalue	Difference	Proportion	Cumulative	Variables
1	4.79405	4.32816	0.7990	0.7990	Regulatory Quality
2	0.465888	0.105333	0.0776	0.8767	Government Effectiveness
3	0.360555	0.160399	0.0601	0.9367	Control of Corruption
4	0.200157	0.100561	0.0334	0.9701	Rule of law
5	0.0995957	0.0198444	0.0166	0.9867	Voice and Accountability
6	0.0797513		0.0133	1.0000	Political Stability

Kaiser–Meyer–Olkin measure of sampling adequacy 0.8927

Table 3.2: Study variables, code, measurement, and sources.

Variables	Code	Measurement	source
Green economy	GG	It is measured by subtracting the monetary value of minerals such as coal, oil, and natural gas depletion, deforestation, and carbon dioxide emissions from the sum of GDP and education expenditure.	Vaghefi et al.,(2015)
GDP per capita	GDP	constant 2015 US\$	WDI
Trade	TOP	Imports + Export (% of GDP)	WDI
Foreign direct investment	FDI	Net inflows (% of GDP)	WDI
Institutional Quality	INST	Index	WGI
Green innovation	INV	Total patent	OECD
Renewable Energy Consumption	REE	% of total	WDI
Population	POP	Millions	WDI
Natural resources rents	NRS	% of GDP	WDI

However, the high correlation among individual governance indicators poses multicollinearity concerns when included separately in a model. To mitigate this, the study follows the methodology outlined by Tawiah et al. (2021), employing principal

component analysis (PCA) to create a composite index. This index accurately captures institutional quality by transforming correlated variables into uncorrelated components. The results of the PCA, presented in Table 3.1, exhibit a Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy at 89%, surpassing the recommended threshold of 50%, affirming the sample's adequacy for PCA. Consequently, various indicators of institutional quality are amalgamated into a singular, comprehensive indicator. Table 3.2. provides details of the variables, their codes, and sources.

3.3.2 Econometric models

This paper examines the role of green innovation, renewable energy, and institutional quality on green growth, considering both short-term and long-term effects. The proposed green growth function, which represents the relationship between the dependent and independent variables, is as follows:

$$GG_{it} = f(GDP_{it}, TOP_{it}, FDI_{it}, INST_{it}, INV_{it}, REE_{it}, POP_{it}, NRS_{it}) \quad (3.2)$$

where GG stands for green growth, GDP per capita measure for economic growth, TOP measures trade openness, FDI captures foreign direct investment, $INST$ assesses institutional quality, INV focuses on green innovation, REE is renewable energy, POP denotes population, and NRS means natural resource rent. To address concerns related to heteroscedasticity, a natural logarithm transformation is applied to all parameters except for $INST$ and FDI , which have small values. This transformation mitigates heteroscedasticity problems and allows the construction of an augmented multivariate function within the panel framework. The functional form of the transformed model is as follows:

$$\begin{aligned} \ln GG_{it} = & \alpha_0 + \alpha_1 \ln GDP_{it} + \alpha_2 \ln TOP_{it} + \alpha_3 FDI_{it} + \alpha_4 INST_{it} \\ & + \alpha_7 \ln POP_{it} + \alpha_8 \ln NRS_{it} + \varepsilon_{it} \end{aligned} \quad (3.3)$$

where $\alpha_0, \dots, \alpha_8$ signify the green growth parameter regarding GDP , TOP , FDI , $INST$, INV , REE , POP , and NRS , respectively. The subscript i corresponds to individual cross-section countries, while the subscript t indicates periods ranging from 2000 to 2021.

3.3.3 Cross-sectional dependency

The CD is the correlation between the error terms of different cross-sectional units in a panel dataset (Pesaran, 2007a). CD is a common problem in panel data analysis. This is particularly true for African countries due to their similar socioeconomic and geographic characteristics. If a CD is present, it can bias the results of panel data estimators. Therefore, to address the potential problems associated with CD, the first step in our analysis is to test the null hypothesis of no CD against the existence of CD. The present study adopts the CD test introduced by Pesaran (2020).

$$CD = \sqrt{\frac{2T}{N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}^2 \right)} \rightarrow N(0,1)_{i,j} \quad (3.4)$$

$$CD = 1,2,3 \dots 52 \dots N \quad (3.5)$$

$$CD = \sqrt{\frac{2T}{N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right)} \frac{(T-K)\hat{\rho}_{ij}^2 - E(T-K)\hat{\rho}_{ij}^2}{Var(T-K)\hat{\rho}_{ij}^2} \quad (3.6)$$

Where, $\hat{\rho}_{ij}^2$ is the correlation coefficient between residuals.

3.3.4 Slope homogeneity

Following the CD test, the study scrutinizes the homogeneity of slope coefficients using the Hashem Pesaran & Yamagata (2008) slope heterogeneity test. This test is favored over the seemingly unrelated regression equation (SURE) method because it eliminates the possibility of cross-sectional dependency (Ahmad et al., 2020). The homogeneity model for this test is formulated as follows:

$$\Delta_{hp} = (N)^{1/2} (2K)^{-1/2} \left(\frac{1}{N} S - K \right) \quad (3.7)$$

$$\Delta_{hp/I} = (N)^{1/2} \left(\frac{2K(T-K-1)}{t+1} \right)^{-1/2} \left(\frac{1}{N} S - K \right) \quad (3.8)$$

Δ_{hp} indicates the tilde delta, while $\Delta_{hp/I}$ signifies the adjusted tilde delta.

3.3.5 Unit-root test

After testing CD and slope heterogeneity, the next stage is to test the cointegration order of the relevant variables. In the presence of CD, first-generation unit root tests may incorrectly reject the null hypothesis and assume independence. This can lead to misleading inferences, as the tests may inaccurately indicate stationarity while ignoring the effects of cross-sectional dependencies (Esmaili et al., 2023). To overcome these limitations, the present study adopted a second-generation unit root test of "Cross-Sectionally Augmented Dicky-Fuller (CADF) and the Cross-Sectionally Augmented IPS (CIPS) tests" by Pesaran (2007). CADF and CIPS tests are designed to address CD and data stationarity. Unlike their first-generation counterparts, these tests account for the data's possible interdependencies or cross-sectional dependence through parametric and nonparametric approaches (Khan et al., 2020). The CADF and CIPS tests operate under the null hypothesis of a homogeneous unit root for all panel members. Nonetheless, the alternative hypothesis posits the existence of at least one stationary panel member. The CIPS equation is as follows.

$$Y_{i,t} = \delta_i + \delta_i x_{i,t-1} + \delta_i \bar{x}_{t-1} + \sum_{l=0} \delta_{il} \Delta \bar{Y}_{t-1} + \sum_{l=0} \delta_{il} \Delta Y_{i,t-1} + \mu_{it} \quad (3.9)$$

The subsequent CIPS statistics can be calculated:

$$\text{CIPS} = N^{-1} \sum_{i=1}^{N-1} t_i(N, T) \quad (3.10)$$

3.3.6 Cointegration test

Cointegration analysis in econometrics, especially with panel data, has become increasingly important for accurate modeling (Esmaeili et al., 2023). While some tests like Kao (1999) and Pedroni (2000) are commonly used, they may have limitations in the presence of cross-sectional dependence (CD).

To overcome these limitations, Westerlund's cointegration tests offer a robust alternative, capable of handling both panel heterogeneity and CD (Westerlund, 2007). This test examine cointegration without typical factor constraints and verify the presence of error correction for integrated series at order 0 or 1 by using two-panel means (p_t and p_a) and two-group means (G_t and G_a) (Khan et al., 2020). The panel means test indicates whether the entire panel is cointegrated, while the group means test determines if at least one element exhibits cointegration (Khan et al., 2020). Acceptance of the alternative hypothesis indicates evidence of long-term cointegration among the variables. The following equation can represent Westerlund's (2007) test specifications:

$$GG_{it} = \alpha_{0i} + \sum_{i=1}^p \alpha_i \Delta GG_{I t-i} + \sum_{i=1}^r \varphi_i \Delta Y_{I t-i} + \lambda_i ECM_{I t-i} + \mu_{i1} \quad (3.11)$$

Where, Y represents the vector of independent variables and λ_i denotes the error-term adjustment speed. If $\lambda_i = 0$, the variables are not cointegrated, whereas if $\lambda_i < 0$, the variables are cointegrated. The test statistics are:

$$G_t = \frac{1}{N} \sum_{i=1}^N \frac{\alpha_i}{SE(\alpha_i)} \quad (3.12)$$

$$G_a = \frac{1}{N} \sum_{i=1}^N \frac{T\alpha_i}{\alpha_i(1)} \quad (3.13)$$

$$P_t = \frac{\alpha}{SE(\alpha)} \quad (3.14)$$

$$P_a = T\alpha \quad (3.15)$$

3.3.7 Estimation technique

Once it is established that all variables are integrated, the subsequent step involves computing the long-run and short-run coefficients using an appropriate method. In this study, we employ the autoregressive distributed lag (ARDL) approach applied within the framework of "maximum likelihood estimation (MLE)" as developed by Pesaran et al. (1999). The ARDL panel offers three different methods for estimation: the mean group (MG) estimator, the pooled mean group (PMG) estimator, and the dynamic fixed effect (DFE) estimator. These methods address heterogeneity bias by allowing for differences in parameter estimates across countries. also they provide accurate forecasts for variables integrated at order 0 or 1, effectively deal with cross-sectional dependence and slope heterogeneity, and maintain validity, efficiency, and consistency in the presence of no stationarity and endogeneity concerns (Bangake & Eggoh, 2012; Xing et al., 2017).

The MG estimator accounts for heterogeneity across countries in both short-run and long-run parameters by computing individual regressions for each country (Erülgen et al., 2020). It allows for variation in slopes and intercepts, making it suitable for panels with significant heterogeneity. The PMG estimator assumes homogeneity in long-run parameters but allows for short-run heterogeneity. It combines pooling and averaging coefficients, assuming similar long-run impacts across all countries (Esmaeili et al., 2023; Udejaja & Isah, 2022). The DFE estimator extends the PMG approach by assuming uniformity in both short and long run across all countries (Esmaeili et al., 2023). The choice of estimator depends on the results of the Hausman test.

The panel ARDL estimation equation is specified as follows:

$$\begin{aligned}
\Delta LNGG_{it} = & \alpha_i + \alpha_{1i}LNGG_{it-1} + \alpha_{2i}LNGDP_{I,-1} + \alpha_{3i}TOP_{I,-1} \\
& + \alpha_{4i}FDI_{I,-1} + \alpha_{5i}INST_{I,-1} + \alpha_{6i}LNINV_{I,-1} \\
& + \alpha_{7i}REE_{I,-1} + \alpha_{7i}LNPOP_{I,-1} + \alpha_{8i}NRS_{I,-1} \\
& + \sum_{j=1}^{P_1} \beta_{1j}\Delta LNGGDP_{it-1} + \sum_{j=1}^{P_2} \beta_{2j}\Delta LNGDP_{I,-1} \\
& + \sum_{j=1}^{P_3} \beta_{3j}\Delta TOP_{I,-1} + \sum_{j=1}^{P_4} \beta_{4j}\Delta FDI_{I,-1} \\
& + \sum_{j=1}^{P_5} \beta_{5j}\Delta INST_{I,-1} + \sum_{j=1}^{P_6} \beta_{6j}\Delta LNINV_{I,-1} \\
& + \sum_{j=1}^{P_7} \beta_{7j}\Delta REE_{I,-1} + \sum_{j=1}^{P_8} \beta_{8j}\Delta LNPOP_{I,-1} \\
& + \sum_{j=1}^{P_9} \beta_{9j}\Delta NRS_{I,-1} + e_{it}
\end{aligned} \tag{3.16}$$

where Δ represents the first differences, α_i is a constant, β_{nij} ($n=1,9$) represents short-run coefficients, α_{m_i} ($m = 1 \dots 9$) shows long-run coefficients and e_{it} denotes the error term. The optimal lag orders for the first differencing are determined using the Schwarz and Akaike information criterion. By including error correction terms, equation 7 can be rewritten as follows:

$$\begin{aligned}
\Delta LNGG_{it} = & \lambda_i + \sum_{j=1}^{P_1} \beta_{1j} \Delta LNGG_{it-1} + \sum_{j=1}^{P_2} \beta_{2j} \Delta LNGDP_{I,-1} \\
& + \sum_{j=1}^{P_3} \beta_{3j} \Delta TOP_{I,-1} + \sum_{j=1}^{P_4} \beta_{4j} \Delta FDI_{I,-1} \\
& + \sum_{j=1}^{P_5} \beta_{5j} \Delta INST_{I,-1} + \sum_{j=1}^{P_6} \beta_{6j} \Delta LNINV_{I,-1} \\
& + \sum_{j=1}^{P_7} \beta_{7j} \Delta REE_{I,-1} + \sum_{j=1}^{P_8} \beta_{8j} \Delta LNPOP_{I,-1} \\
& + \sum_{j=1}^{P_9} \beta_{9j} \Delta NRS_{I,-1} + \mu_i ECT_{it,-1} + e_{it}
\end{aligned} \tag{3.17}$$

where $ECT_{it,-1}$ is the error correction term.

3.3.8 Robustness check

To ensure robustness, this study employs the generalized method of moments (GMM), fixed effects (FE), and augmented mean group (AMG) method. These approaches are versatile in handling issues like heterogeneity, non-stationarity, endogeneity, and CD, enhancing reliability by systematically addressing them (Acheampong, 2022; Arellano & Bond, 1991; Esmaeili et al., 2023; Roodman, 2009)

3.3.9 Causality test

This study employs the panel Granger causality test introduced by Dumitrescu & Hurlin (2012) to investigate the cause-and-effect dynamics among variables and their respective directions. This test proves especially useful when error terms exhibit CD. The DH Granger causality test assumes a null hypothesis stating the absence of a causal relationship between variables. In contrast, the alternative hypothesis suggests the presence of a causal link among the variables. The equation for the DH Granger causality test is as follows:

$$x_{i,t} = \alpha_i + \sum_{k=1}^p \alpha_i^k x_{i,t-k} + \sum_{j=1}^p z_i^j T_{i,t-j} \quad (2.18)$$

In the equation, 'j' signifies the lag length, while α^j (j) denotes the autoregressive parameters.

3.4 Results and Discussion

3.4.1 Descriptive statistics

Table 3.3 presents a comprehensive summary of descriptive statistics for the variables employed in this study. The mean of the logarithm of green growth (LNGG) is 2.251, with a corresponding standard deviation of 1.64. FDI displays the highest standard deviation, while LNTOP registers the lowest value.

The criteria for a series conforming to a normal distribution involve a skewness value of 0 and a kurtosis value of 3 (Mensah et al., 2019). Upon analyzing specific variables, LNGG, LNGDP, LNTOP, FDI, and INST exhibit positive skewness, indicating a right-leaning tendency compared to a normal distribution. Conversely, LNINV, LNREE, LNPOP, and LNNRS show negative skewness, suggesting a left-leaning distribution.

Table 3.3: Descriptive statistics.

Variables	LNGG	LNGDP	LNTOP	FDI	INST	LNINV	LNREE	LNPOP
Obs	1,078	1,078	1,078	1,078	1,078	1,078	1,078	1,078
Mean	2.251	7.217	3.866	4.262	-1.1	3.461	3.717	1.595
SD	1.64	1.004	0.485	7.819	2.19	0.486	1.243	1.595
Min	-2.526	5.542	2.055	-26.64	-1.8	1.609	-2.813	11.29
Max	6.256	9.740	5.234	86.99	1.9	4.357	4.588	19.17
Skewness	0.037	0.539	0.044	5.244	0.447	-1.012	-2.426	-0.707
Kurtosis	2.791	2.411	2.891	44.541	2.725	4.269	9.378	3.302
Jarque-Bera	2.40	63.48	0.80	879.83	31.71	128.05	420.59	63.46
Probability	0.3010	0.0000	0.6689	0.0000	0.0000	0.0000	0.0000	0.0000

Furthermore, the kurtosis values for LNGG, LNGDP, LNTOP, and INST are below 3, indicating a platykurtic distribution characterized by a flatter peak. In contrast, FDI,

LNINV, LNREE, LNPOP, and LNNRS display kurtosis values exceeding the standard threshold, signifying a leptokurtic distribution with heavier tails. Considering both kurtosis and skewness values, none of the variables meet the conditions for a normal distribution. Additionally, evidence from the Jarque Bera test supports the conclusion that, except for LNGG and LNTOP, none of the series is normally distributed, as the null hypothesis of normality is rejected for the remaining variables.

3.4.2 Econometric result and dissuasion

Table 3.4 displays the findings of the CD test. The result shows that the null hypothesis of no CD is rejected for all variables, indicating that the variables in the panel dataset are interdependent. This implies that an economic shock occurring in one country can spill over to the economies of other countries within the region. The slope heterogeneity test outcomes also reveal statistically significant values for delta and adjusted delta. These results indicate the presence of a slope heterogeneity issue. Consequently, CD and slope heterogeneity highlight the need for second-generation unit root tests to assess variable stationarity in panel data.

Table 3.4: Cross-sectional dependence and slope homogeneity test.

Variables	CD-test	Correlation	Slope homogeneity Test	
			Hashem Pesaran & Yamagata (2008) Test	Statics
LNGG	115.021***	0.72	Delta	9.042***
LNGDP	113.515***	0.71	Adj. Delta	13.479***
LNTOP	19.667***	0.12		
FDI	10.704***	0.07		
INST	0.332	0.00		
LNINV	47.264***	0.29		
LNREE	64.434***	0.40		
LNPOP	157.882***	0.98		

Table 3.5 presents the results of the CADF and CIPS tests, wherein lagged variables are incorporated to address potential serial correlations. The findings indicate that all observed variables exhibit stationarity at the mixed level. Specifically, while some variables are stationary in their original form, all variables demonstrate stationarity when they differ at one. Consequently, the null hypothesis of nonstationary series is

rejected, indicating that these series possess an integration order of either 0 or 1. Therefore, using the ARDL method for estimating the underlying model does not result in misleading regression outcomes, as none of them are integrated into order 2.

Table 3.5: CADF and CIPS test results.

Variables	CADF		CIPS		
	Level	First difference	Level	First difference	
LNGG	-0.725	-2.462***	-0.983	-3.176***	<i>l</i> (1)
LNGDP	-0.845	-2.378***	-1.185**	-3.372***	<i>l</i> (0)
LNTOP	-1.420	-2.535***	-1.3**	-4.443***	<i>l</i> (1)
FDI	-1.839**	-2.500***	-2.478***	-5.118***	<i>l</i> (0)
INST	-1.829**	-2.090***	-0.900	-3.883***	<i>l</i> (0)
LNINV	-2.125***	-2.828***	-1.942***	-4.494***	<i>l</i> (0)
LNREE	-1.962***	-2.188***	-1.462*	-3.853***	<i>l</i> (0)
LNPOP	-2.253***	-2.523***	-0.519	-2.230***	<i>l</i> (0)
LNNRS	-2.227***	-3.190***	-2.258***	-4.021***	

***, **, * explains the level of significance at 1%, 5% and 10%, respectively

The Westerlund cointegration test results in Table 3.6 show that the study variables are cointegrated, indicating a long-run relationship. Therefore, assessing the short—and long-run impacts of the independent variables on green growth is essential.

Table 3.6: Westerlund (2007) cointegration test results.

	T statics	p-value	Decision
Gt	-1.6928**	0.0453	Cointegration
Ga	-2.3388***	0.0097	Cointegration
Pt	-1.9805**	0.0238	Cointegration
Pa	-1.8169**	0.0346	Cointegration

***, **, * explains the level of significance at 1%, 5% and 10%, respectively

The long-run and short-run relations among variables are estimated through subsequent cointegration analysis. Table 3.7 displays the ARDL model results with error corrections (p, q) using PMG, MG, and DFE. The study's findings suggest that the PMG estimator is the most appropriate model for estimating long- and short-term relationships among the variables of interest. The Hausman-1 and Hausman-2 test

results support this. The error correction term (ECT) coefficient indicates the system's tendency to approach its equilibrium level in the long run. Specifically, an ECT coefficient falling between 0 and -1 signifies convergence to the equilibrium level (Esmaeili et al., 2023). The ECT coefficient of -0.06 in the PMG results suggest that the system converges to its long-run equilibrium, implying that any deviations from equilibrium will be corrected over time.

The empirical results indicate that the coefficients of GDP per capita, institutional quality, and population are positive and statistically significant in the short and long run. However, the coefficient of natural resource rents is negative and statistically significant. Additionally, while the coefficients associated with green technological innovation, renewable energy consumption, and trade openness are positive in the long run, their short-run counterparts are negative. Conversely, the FDI coefficient is harmful in the long run, while its short-run counterpart is positive. Notably, all variables have a statistically significant impact on green growth in the long run. In contrast, only economic growth and institutional quality statistically significantly affect green growth in the short run.

Institutional quality positively and significantly affects green growth in the short and long term. This is likely because robust institutions provide a stable and predictable business environment and foster investment in sustainable technologies and practices. As a result, this enhances efficiency, reduces waste, and ultimately promotes higher levels of green growth. Moreover, strong institutions can enforce and ensure compliance with environmental regulations, thereby mitigating negative externalities associated with economic activities. High-quality institutions are also crucial in adopting and monitoring policies that reduce carbon emissions and encourage climate-friendly investments. By doing so, they contribute to cultivating climate change adaptation culture and fostering sustainable development. This result aligns with the recent findings that institutional quality plays a significant role in determining green growth (for instance, Ahmed et al., 2022; Azam et al., 2021).

Table 3.7: PMG, MG, and DFE results (1,1,1,1,1,1,1,1).

Variables	PMG	MG	DFE
Short Run Impact			
Δ LNGDP	0.198*** (0.0417)	0.0261 (0.0755)	0.00958*** (0.000471)
Δ LNTOP	-0.000662 (0.000697)	0.000457 (0.00129)	-0.00151* (0.000914)
Δ FDI	0.000393 (0.00178)	0.00574 (0.00498)	7.08e-05 (0.00140)
Δ INST	0.0390** (0.0183)	0.00635 (0.0278)	-0.00492 (0.0301)
Δ LNINV	-0.00690 (0.0416)	0.0691 (0.121)	-0.00501 (0.0452)
Δ LNREE	-0.0501 (0.158)	-0.0431 (0.276)	-0.150 (0.0964)
Δ LNPOP	1.331 (3.236)	24.04** (9.666)	-1.128 (1.086)
Δ LNNRS	-0.0900*** (0.0228)	-0.0725* (0.0389)	-0.0736** (0.0294)
Short run adjustment	-0.0642***	-0.620***	-0.131***
Long run Impact			
LNGDP	0.00515*** (0.000699)	0.192*** (0.0491)	0.00588*** (0.00217)
LNTOP	0.00643*** (0.00211)	0.00296 (0.00510)	0.000109 (0.00613)
FDI	-0.0135*** (0.00405)	-0.0335 (0.0458)	0.00383 (0.0108)
INST	0.122*** (0.0295)	0.0298 (0.0818)	0.177 (0.109)
LNINV	0.234*** (0.0656)	-0.489 (0.475)	0.289 (0.281)
LNREE	1.095*** (0.228)	1.802* (1.049)	0.556 (0.392)
LNPOP	1.244*** (0.171)	1.767* (0.947)	0.514 (0.707)
LNNRS	-0.169*** (0.0513)	-0.0102 (0.180)	-0.186 (0.161)
Constant	-0.437*** (0.162)	-1.822 (2.438)	0.281 (0.287)
No.Observations	1,028	1,028	1,028
No.Countries	49	49	49
Housman test 1	(PMG or MG) 0,460 (prob> chi ² = 0.99)		
Housman test 2	(PMG or DFE) 0.26 (Prob > chi ² = 0.753)		

***, **, * explains the level of significance at 1%, 5% and 10%, respectively

While green innovation initially lacks significant short-term benefits, its long-term positive impact on green growth is statistically significant, indicating its crucial role in sustainable development and environmental goal attainment. The observed initial negativity and insignificance can be attributed to the time required for technological adoption and integration into the economy, alongside substantial upfront investment demands, which may deter some companies from investing. In Africa, technological innovation gaps hinder firms' ability to innovate in green growth (Obobisa et al., 2022). Nevertheless, as the benefits of green innovation become more apparent over time, significant improvements in environmental sustainability and economic growth will be realized. Also, promoting zero-emission technologies through green patents and technological innovation can transform African industrial and manufacturing structures into more sustainable ones. This assertion is supported by the aforementioned empirical evidence (Ahmed et al., 2021; Mohamed et al., 2022) and the theory of environmental modernization (as proposed by Porter and Van Der Linde, 1995).

The PMG result further reveals that long-term renewable energy is strongly associated with green growth, while the short-term impact is insignificant. The coefficient findings show that a 1% rise in renewable energy corresponds to a significant 1.16% annual growth in the green sector within the examined economy. This indicates a strong positive relationship between adopting renewable energy sources and promoting green growth. This compelling finding underscores a robust positive relationship between transitioning to renewable energy sources and promoting sustainable economic growth initiatives. Initially, implementing renewable energy may not immediately yield considerable green growth outcomes due to the entailed upfront investments, infrastructure developments, and the time required for materializing efficiency gains. However, in the long term, the benefits of renewable energy would unfold as production costs are reduced and environmental benefits are realized. In this regard, the findings of Mumuni & Mwimba (2022) and Sunday et al. (2022) show that certain African countries have recently embraced renewable energy as a viable alternative to conventional fossil fuels, contributing to favorable outcomes regarding green growth.

The result from the control variables also exhibits significant effects on green growth. Trade openness has a negative and insignificant influence on green growth in the short

run but a positive and significant impact in the long run. While Tawiah et al. (2021) found a negative short-run impact of trade on green growth, our study contradicts this, indicating a positive long-run effect. Initially, trade may lead to pollution due to specialized export industries in Africa with fewer environmental regulations. However, over time, exposure to stricter environmental standards from major importers encourages the adoption of cleaner production methods. Trade also facilitates the exchange of knowledge and technology, introducing more efficient and environmentally friendly practices. Mumuni & Mwimba (2022) similarly concluded that trade openness positively impacts long-term growth in Africa.

Regarding FDI, its short-term effects are negative and insignificant but become significantly negative in the long term. This aligns with the pollution haven hypothesis, indicating that foreign companies in African nations exploit relaxed environmental regulations, leading to pollution. FDI in Africa often targets resource extraction and export-oriented industries, exacerbating ecological degradation and resource depletion. Multinational corporations may prioritize profits over sustainability, contributing to further environmental harm. Our findings are aligned with those of Ofori et al.(2023). Additionally, natural resource rent consistently impedes green growth, attributed to limited economic diversification in African economies, aligning with Singh et al. (2023).

However, our findings reveal a positive and statistically significant relationship between GDP per capita and green growth in both the short and long term. The positive impact of GDP per capita on green growth is linked to increased government spending on environmental protection, higher consumer demand for sustainable products, and improved environmental awareness in the short term. In the long term, economic growth drives technological innovation, economic transformation, and institutional development, all contributing to a cleaner and more sustainable economic model. It can also enable countries to implement policies and initiatives that promote sustainable development and address environmental challenges.

Regarding population growth, it exhibits a negative and statistically insignificant effect on green growth in the short run but a positive and statistically significant impact in the long run. One possible explanation for this finding is that population growth in the short run may lead to increased resource consumption and environmental degradation, which can offset any potential benefits for green growth. However, population growth

may stimulate innovation and technological advancements in the long run, leading to more sustainable and environmentally friendly practices, ultimately promoting green growth. The empirical evidence presented by Tawiah et al. (2021) also supports the positive relationship between economic growth and green growth performance.

3.4.3 Robustness checks with alternative models

This study also considers two-step GMM, fixed effects, and AMG estimation to check the signs of the variables and robustness of the PMG approach. While the GMM method confirms the short run, the fixed effect and AMG methods ensure the coefficients' signs in the long run.

Table 3.8: GMM, FE, and AMG results.

Variables	GMM	FE	AMG
L.LNGGDP	0.567*** (0.0418)		
LNGDP	0.00309*** (0.000434)	0.00496*** (0.000339)	0.196*** (0.0425)
LNTOP	0.00235*** (0.000681)	-0.00157* (0.000940)	-0.00163 (0.00123)
FDI	-0.00402*** (0.00142)	0.000362 (0.00168)	0.00153 (0.00310)
INST	0.101*** (0.0242)	0.110*** (0.0185)	0.0506* (0.0282)
LNINV	-0.108 (0.0700)	-0.177*** (0.0408)	-0.0127 (0.0402)
LNREE	-0.105*** (0.0196)	-0.336*** (0.0659)	0.315 (0.488)
LNPOP	0.302*** (0.0474)	2.411*** (0.0764)	-0.198 (0.157)
LNNRS	0.0252 (0.0205)	0.0668*** (0.0247)	-0.0889*** (0.0242)
Constant	0.867*** (0.275)	-1.282*** (0.363)	0.555 (2.290)
Number of ID	49	49	49
No. Instruments	31		
AR (1)	0.000		
AR (2)	0.653		
Hansen Test	0.599		
Observations	1,029	1,078	1,078
R-squared		0.683	

***, **, * explains the level of significance at 1%, 5% and 10% respectively.

The findings for most variables closely align with the PMG estimates, irrespective of specific coefficient values. We also utilized Granger causality tests to investigate the long-term relationships between explanatory variables and African green growth. The results in Table 3.9 indicate bidirectional causal relationships between the explanatory variables examined in the study and green growth. Therefore, it can be inferred that green innovation, institutional quality, renewable energy consumption GDP per capita, trade openness, FDI, population, and natural resource rents affect green growth and vice versa. These findings are consistent with previous studies by Ahmad et al. (2022) and Le & Van (2020).

Table 3.9: Results of the Dumitrescu–Hurlin panel causality test.

Null Hypothesis:	W-Stat.	Zbar-Stat	Result	Conclusion
LNGG ≠ GDP	2.5371***	7.6084***	yes	LNGG causes LNGDP
GDP ≠ LNGG	2.616***	7.9986***	yes	LNGDP causes LNGG
LNGG ≠ LNTOP	2.7224***	8.5253***	yes	LNGG causes LNTOP
LNTOP ≠ LNGG	2.9931***	9.8654***	yes	LNTOP causes LNGG
LNGG ≠ FDI	1.79***	3.9103***	yes	LNGG causes FDI
FDI ≠ LNGG	2.2451***	6.1631***	yes	FDI causes LNGG
LNGGDP ≠ INST	1.762***	3.7715***	yes	LNGG causes INST
INST ≠ LNGG	4.104***	15.3641***	yes	INST causes LNGG
LNGG ≠ LNINV	2.5008***	7.4284***	yes	LNGG causes LNINV
LNINV ≠ LNGG	2.1931***	5.9053***	yes	LNINV causes LNGG
LNGGDP ≠ LNREE	1.4715***	2.3337***	yes	LNGG causes LNREE
LNREE ≠ LNGG	3.1527***	10.6554***	yes	LNREE causes LNGG
LNGG ≠ LNPOP	4.8883***	19.2459***	yes	LNGG causes LNPOP
LNPOP ≠ LNGG	15.9711***	74.1031***	yes	LNPOP causes LNGG
LNGG ≠ LNNRS	2.1386***	5.6359***	yes	LNGG causes LNNRS
LNNRS ≠ LNGG	2.3399***	6.6321***	yes	LNNRS causes LNGG
LNGG ≠ GDP	2.5371***	7.6084***	yes	LNGG causes LNGDP
GDP ≠ LNGG	2.616***	7.9986***	yes	LNGDP causes LNGG
LNGG ≠ LNTOP	2.7224***	8.5253***	yes	LNGG causes LNTOP
LNTOP ≠ LNGG	2.9931***	9.8654***	yes	LNTOP causes LNGG
LNGG ≠ FDI	1.79***	3.9103***	yes	LNGG causes FDI
FDI ≠ LNGG	2.2451***	6.1631***	yes	FDI causes LNGG
LNGGDP ≠ INST	1.762***	3.7715***	yes	LNGG causes INST
INST ≠ LNGG	4.104***	15.3641***	yes	INST causes LNGG
LNGG ≠ LNINV	2.5008***	7.4284***	yes	LNGG causes LNINV
LNINV ≠ LNGG	2.1931***	5.9053***	yes	LNINV causes LNGG
LNGGDP ≠ LNREE	1.4715***	2.3337***	yes	LNGG causes LNREE
LNREE ≠ LNGG	3.1527***	10.6554***	yes	LNREE causes LNGG
LNGG ≠ LNPOP	4.8883***	19.2459***	yes	LNGG causes LNPOP
LNPOP ≠ LNGG	15.9711***	74.1031***	yes	LNPOP causes LNGG
LNGG ≠ LNNRS	2.1386***	5.6359***	yes	LNGG causes LNNRS
LNNRS ≠ LNGG	2.3399***	6.6321***	yes	LNNRS causes LNGG

***, **, * explains the level of significance at 1%, 5% and 10%, respectively

3.5 Conclusion and Policy Implications

By fostering economic prosperity while safeguarding the environment, green growth generates a holistic strategy for economic development. As such, green growth has developed as a critical paradigm for sustainable development. Therefore, understanding the factors that drive green growth is crucial. This study investigates the short- and long-term factors influencing green growth in Africa, focusing on institutional quality, green innovation, and renewable energy consumption. In addition, the influence of GDP per capita, trade liberalization, FDI, population size, and natural resource rents are also considered.

The finding shows that solid institutions are pivotal for fostering short- and long-term green growth. While green innovation exhibits a negative and statistically insignificant short-term effect, its long-term impact is positive and statistically significant, highlighting the need for long-term investment strategies. Long-term cost reductions that drive the use of renewable energy are also positively related to green growth. However, its short-term impact could be negative due to upfront investment and infrastructure demands. The impact of trade presents a complex picture. Short-term trade liberalization might contribute to environmental degradation, but long-term benefits emerge due to stricter environmental standards and knowledge transfer facilitated by trade. FDI exhibits a negative and significant long-term impact, aligning with the "pollution haven hypothesis." Meanwhile, natural resource rents consistently hinder green growth across both timeframes. GDP per capita displays a positive and significant relationship with green growth in the short and long term. Despite exhibiting a negative and insignificant effect in the short term, population growth surprisingly shows a positive and significant impact in the long run, suggesting the potential for population pressure to stimulate innovation and sustainable practices, ultimately promoting green growth.

Based on these findings, the study offers the following policy recommendations: First, investment in robust and transparent institutions is crucial to creating a stable and predictable environment for long-term green growth strategies. This could involve strengthening regulatory frameworks, promoting good governance, and fostering public-private partnerships for sustainable development. Second, despite initial challenges, long-term investment in green innovation is crucial to bridge the

innovation gap and promoting sustainable practices. In this regard, policies should encourage long-term support for research, development, and commercialization in this sector. This might encompass tax breaks, grants, and public-private partnerships focused on green technologies. Third, while acknowledging potential short-term challenges associated with upfront costs and infrastructure needs, prioritizing long-term investments in renewable energy infrastructure is essential. Targeted policies addressing cost concerns, such as subsidies or feed-in tariffs, can accelerate the transition. Fourth, promoting trade agreements that prioritize environmental sustainability is crucial to mitigate potential short-term environmental degradation from trade liberalization. These agreements should encourage knowledge transfer and stricter environmental standards among trading partners. Fifth, A cautious approach to FDI is recommended. Governments should meticulously assess the environmental impact of potential FDI projects and ensure alignment with national green growth strategies to avoid attracting "polluting" industries. Sixth, implementing policies that promote resource efficiency and diversification is crucial to decoupling economic growth from unsustainable resource extraction. This could involve exploring alternative revenue streams, investing in green technologies, and adopting sustainable resource management practices. Finally, while acknowledging the potential long-term benefits of population growth in stimulating innovation and sustainable practices, developing policies encouraging responsible resource management is crucial. This may involve investments in education, promoting family planning initiatives, and fostering sustainable urban development.



4. SYMMETRIC AND ASYMMETRIC EFFECTS OF ECONOMIC POLICY UNCERTAINTY, OIL PRICE SHOCKS, AND FDI ON ENVIRONMENTAL SUSTAINABILITY IN SELECTED SUB-SAHARAN AFRICAN COUNTRIES

4.1 Introduction

In recent years, scholarly literature on climate change, ecological instability, and other environmental risks has received growing attention. The consequences of climate change are now more evident and affect not only the economy but also the environment and society. Changes in rainfall and temperature—for example—cause species extinction, habitat degradation, and other disruptions of ecological services like water and food (Bell et al., 2018). These environmental changes also have their economic implications, where the affected people suffer more and thus worsen the social and economic disparities (Carleton & Hsiang, 2016). Additionally, communities have been made worse off by climate change, as it has fueled increased social challenges causing climate-related migration and displacement (Clarke et al., 2022). It is also important to note that air and water pollution as well as food insecurity are expected to be the major world issues in the future.

In view of the increasing threats, the international community has contributed to the formulation of measures like the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted in 1992. Subsequent measures have also changed and developed, going further than just the emission targets and including the provision of funds for combating climate change in developing countries. Most recently, at COP28 in Dubai, nations were urged to accelerate transitions to green energy and adopt sustainable practices.

Despite these efforts, these threats still exist, showing the gap between policy development and the practice of policy worldwide. For instance, developing countries have scarce resources, weak institutional frameworks, and other economic demands that make it difficult to implement climate change policies effectively (Falcone, 2023;

Lamb & Minx, 2020). On the other hand, the same issues are observed in developed countries, although in a different way—they also struggle with GHG emission reduction despite their pledges. Many have failed to achieve targets owing to political barriers and economic challenges (Kelly, 2010). Although the European Union is motivated to reduce emissions, other countries, including the United States and other emerging powers like China and India, show a lack of ambition (Aljefri et al., 2013).

These disparities may be due to the difference in how countries measure and address key environmental sustainability indicators such as greenhouse emissions, biodiversity loss, and consumption of natural resources. Such variation in the capabilities of measuring these indicators may also be present, which could be attributed to technological, economic, and institutional factors. In addition, the factors that shape environmental policy can be quite different in different countries, and this makes it difficult to set up guidelines that would be effective for all. Thus, assessing environmental sustainability indicators and their potential drivers is vital for developing tailored, effective solutions to environmental challenges.

In environmental studies, CO₂ emissions are commonly used as indicator of environmental sustainability. However, recent studies have criticized this approach due to its narrow focus. Hence, the ecological footprint (ECOF) has emerged as a broader measure of environmental sustainability (Amer et al., 2024). For example, while CO₂ emissions reflect direct greenhouse gas emissions, ECOF encompasses additional dimensions such as land use, waste generation, and resource depletion (Adebayo et al., 2024; Yang et al., 2022). CO₂ emissions often also fail to account for other environmental issues such as the release of toxic substances (Laurent et al., 2012). Furthermore, studies have shown that the Environmental Kuznets Curve hypothesis fits better with ECOF than with CO₂ emissions (Altıntaş & Kassouri, 2020; Ansari, 2022). Therefore, focusing on reducing carbon emissions only may not adequately address all aspects of environmental sustainability.

While ECOF offers a broader perspective, it is not without limitations. Many studies highlight concerns about its narrow scope, methodological assumptions, measurement accuracy, and policy relevance (Dam et al., 2024; Wiedmann & Barrett, 2010). This suggests that also ECOF may fail to encompass the full range of environmental sustainability. Therefore, in this study, CO₂ and ECOF were used as environmental sustainability indicators to overcome the above limitations. However, a crucial

question needs to be examined: What are the main drivers for CO₂ and ECOF? How do they respond to these drivers symmetrically as well as asymmetrically?

Many studies have found determinants of environmental suitability including economic policy uncertainty (Chu et al., 2023; Danish et al., 2020; Selmey and Elamer, 2023), Oil price fluctuations (Ebaid et al., 2022; Hu et al., 2022; Yiyang Li et al., 2023; Meng et al., 2024) and Foreign Direct Investment (Duodu et al., 2021; Jorgenson et al., 2022; Ly-My et al., 2024). In general, these studies argue that the importance of including these variables when formulating successful environmental policies and strategies for sustainable development is highlighted.

Economic Policy Uncertainty (EPU) refers to uncertainty regarding monetary or fiscal policy (Q. R. Syed & Bouri, 2022). It is an important, yet under-explored factor influencing environmental sustainability. EPU can affect environmental sustainability through its impact on government policies, corporate strategies, and energy consumption. For instance, during high EPU period, governments may prioritize economic stability by relaxing environmental regulations, which can harm ecological preservation (Benlemlih & Yavaş, 2024). Regulatory control may also weaken in uncertainty period, and hence, a potential to create delay in the adoption of sustainability and green technology. On the other hand, high EPU enhances firms' corporate social responsibility (CSR) due to increased general public awareness (Yuan & Zhang, 2020). This adoption, in turn, may assist firms in sharing risks and enhancing the stakeholders' confidence, thus enhancing environmental governance.

EPU also has an impact on investment decisions. High EPU may enhance capital costs and make investments in green technologies less attractive (Drobetz et al., 2018). However, companies that navigate periods of high EPU may be driven to innovate in green technologies for survival and thus be compelled to contribute to the pursuit of sustainability (Li et al., 2021; Shabir et al., 2022). Furthermore, EPU impacts energy consumption in the enterprises. The uncertainty may make the enterprises select cleaner energy sources in order to ensure cost stability and market risk protection (Xue et al., 2022). On the other hand, increased EPU can decrease that confidence, reduce investment in sustainable technologies, or encourage stricter regulations.

Although this link is frequently ignored in earlier research, oil price volatility has a substantial influence on environmental sustainability. A shift to a more sustainable

energy system can be facilitated by high oil prices, which can increase investment in green technology and promote energy-saving behaviors (Dutta, 2017). On the other hand, low oil prices discourage investment in renewable energy by making fossil fuels more alluring. As customers look for more affordable options, rising oil prices usually lead to a rise in demand for alternatives (Al-Maamary et al., 2017). Furthermore, because governments must strike a balance between short-term economic gains and long-term sustainability objectives, changes in oil prices have an impact on the formulation of environmental policies (Ebrahim et al., 2014).

Besides EPU and oil, foreign direct investment (FDI) is also another determinate factor that potentially affects environmental sustainability. FDI inflows may enhance green innovation, job creation, and research and development in sustainable practices (W. Huo et al., 2022). It has also the potential to facilitate technology transfer and provides necessary capital for investment in eco-efficient technologies. However, unregulated FDI may also lead to higher energy consumption, increased resource utilization, and pollution, thereby expanding the ecological footprint (H. Zhu et al., 2016). Additionally, it may also cause unfair competition with local firms and discourage investment in sustainable development (S. Wang et al., 2020).

Based on these considerations, this study aims to analyze the symmetric and asymmetric relationships between economic policy uncertainty (EPU), oil price shocks, and FDI on environmental sustainability in Sub-Saharan Africa (SSA). There are several reasons for focusing on SSA economies. First, the region has the highest GDP growth rate in the world. However, this growth is heavily reliant on increased energy consumption from non-renewable resources (Alaganthiran et al., 2022; Olanrele & Awode, 2022). Additionally, the region is striving to align its economic development strategies with international environmental goals. Consequently, SSA countries may face a decision on how to shape their development processes without compromising ecological sustainability.

Second, SSA is the least contributor to global greenhouse gas emissions, accounting for less than 3-4% of total carbon emissions (World Bank, 2020). Furthermore, it has the lowest ecological footprint in the world (Yang et al., 2022). Yet, the region's carbon emissions and ecological footprints have been steadily increasing (Figures 4.1 and 4.2). Such growth, however, would lead to concerns about the region's potential climate change and environmental degradation consequences. As a result, it is

important to explore what is causing these trends to take place for the purposes of developing effective mitigation and adaptation strategies for the region.

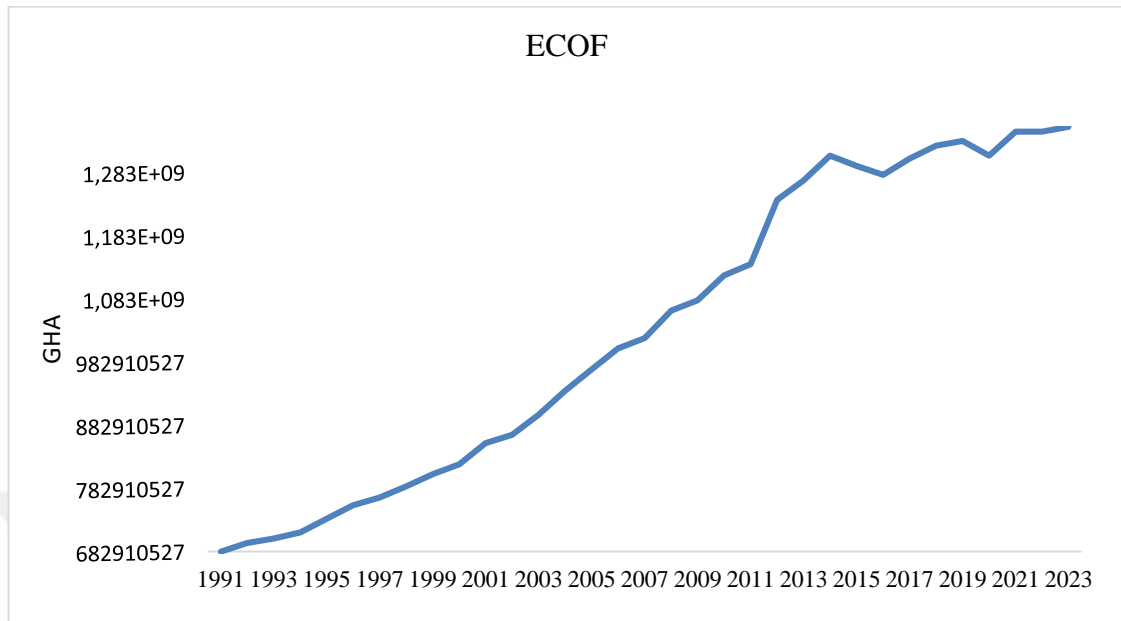


Figure 4.1: Ecological footprint consumption in Sub-Saharan Africa (1991 - 2023).

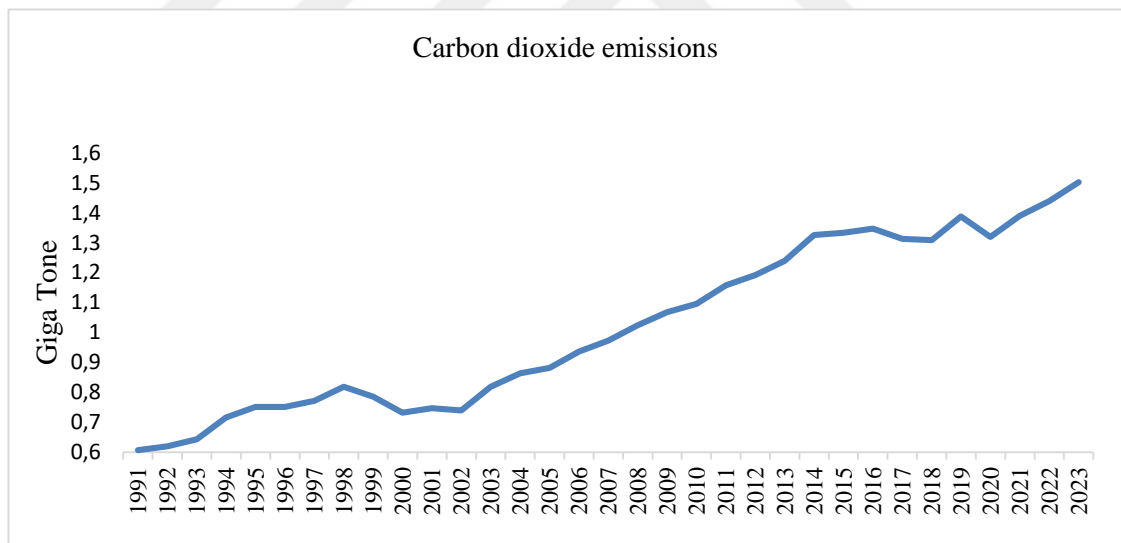


Figure 4.2: CO₂ emissions in Sub-Saharan Africa (1991 - 2023).

Thirdly, SSA heavily relies on fossil fuels, particularly oil, to drive its economy. However, as oil prices are determined internationally, the region has limited control over them. This makes SSA vulnerable to fluctuations in the global oil market, as illustrated in Figure 4.3. These price variations can significantly affect the region's environmental performance by influencing consumer spending, transportation costs, and energy affordability. High oil prices reduce consumer spending, leading to a

decrease in investments in sustainable practices (Akinsola & Odhiambo, 2020). Increased transportation costs further limit access to green technologies (Zhang et al., 2022), while energy accessibility problems prevent change towards cleaner energy sources (Ibrahim et al., 2021). Furthermore, existing literature indicates that oil price shocks impact carbon emissions and ecological footprints, thereby affecting environmental sustainability. This issue is especially pertinent in SSA, where economic growth remains low. However, empirical evidence on the effects of oil price shocks on environmental sustainability in the region remains inconclusive.

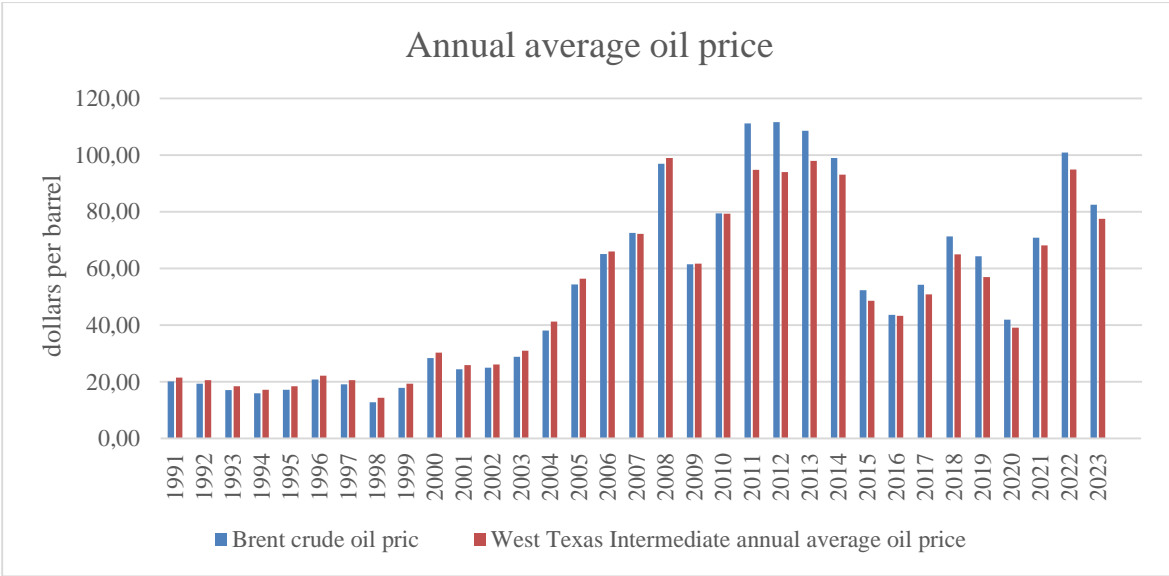


Figure 4.3: Annual average oil price (1991-2023).

Fourth, the region has also faced significant volatility in EPU and FDI inflows (Figures 4.4 and 4.5). This volatility may have intense implications for environmental sustainability. EPU may delay the implementation of green reforms and discourage investments in environmentally sustainable projects. Meanwhile, FDI inflow may promote cleaner technologies or contribute to environmental degradation, depending on how it is managed and regulated. Given SSA's heavy reliance on natural resources and vulnerability to FDI inflow, assessing how EPU and FDI influence environmental sustainability is critical. This insight is vital for developing effective policies encouraging sustainable investments and ensuring economic growth aligns with ecological conservation and global climate objectives.

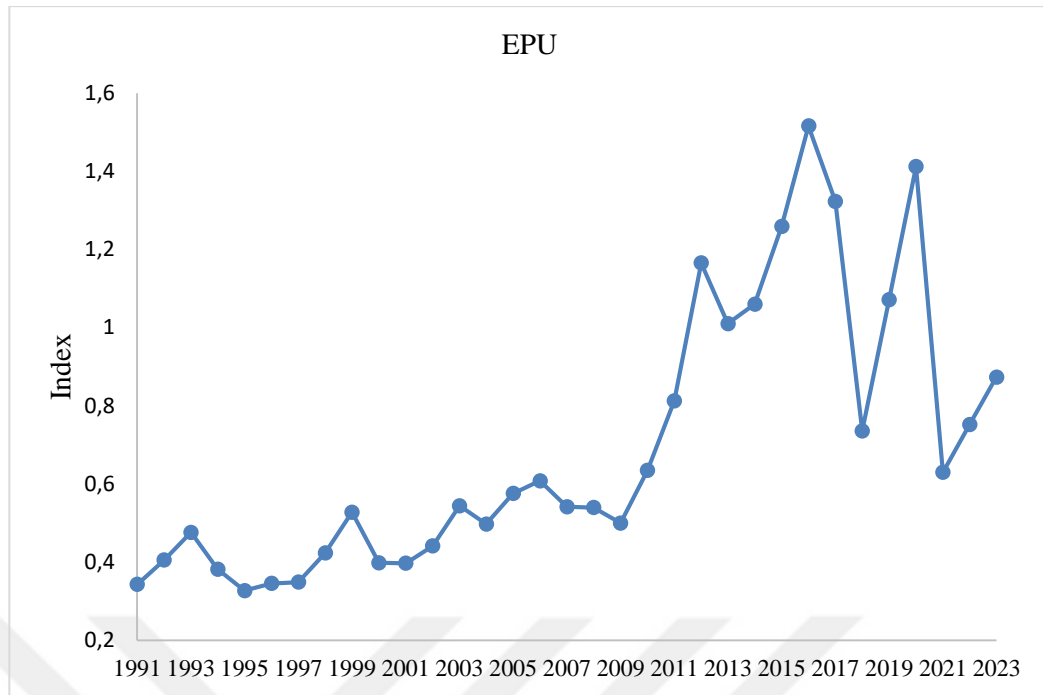


Figure 4.4: Economic policy uncertainty index (1991 - 2023).

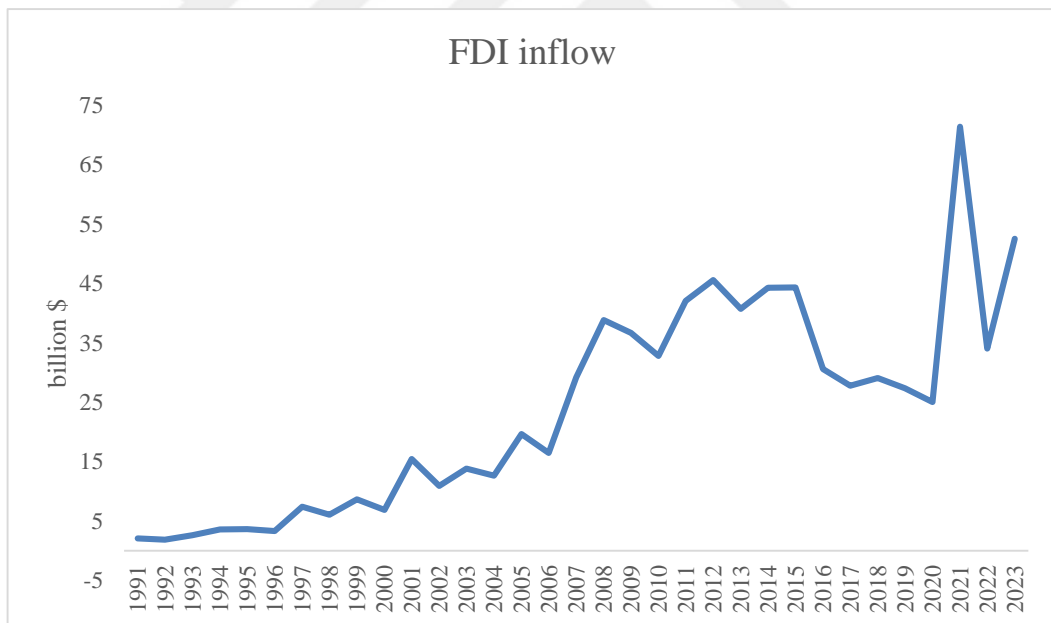


Figure 4.5: Foreign direct inflow in Sub-Saharan Africa (1991 - 2023).

This study offers multiple contributions to the current literature. First, it uses symmetric and asymmetric trends to examine the impacts of EPU, oil prices, and FDI on environmental sustainability. The analysis contends that variations in these characteristics can either facilitate or hinder manufacturing, supply networks, and investments, thus affecting ecological performance. While prior studies have investigated symmetric effects, the asymmetric implications have yet to be addressed.

Therefore, this study provides new insights into the impact of EPU, oil price volatility, and FDI on environmental sustainability in the Sub-Saharan Africa (SSA) region.

Second, this study analyzes the effects of fluctuations in oil prices, investment flows, and governmental policies on emissions and ecological footprints in both the short and long run. Also, this study considers ecological footprints and carbon dioxide emissions as environmental sustainability indicators. This dual focus on ecological footprints and carbon dioxide emissions as environmental sustainability indicators sets the study apart from previous works.

Third, previous studies have used the EPU index constructed by Baker et al.(2016) which is based mainly on uncertainty related to economic policy. This study, however, uses the World Uncertainty Index (WUI) of Ahir et al. (2024) That encompasses economic and political uncertainties. The study analyzes how policy uncertainty and economic factors affect environmental sustainability in Sub-Saharan Africa (SSA) using annual data from 1991 to 2023. The findings of this study also contribute to achieving some SDGs 7(Affordable and Clean Energy), 8 (Decent Work and Economic Growth), and 13 (Climate Action).

The remaining sections are structured as follows: In Section 2, we review the literature. In Section 3, we outline our data and methodology. In Section 4, we present our findings and discussion, and in Section 5, we conclude with policy recommendations.

4.2 Literature Review

4.2.1 Epu and environmental sustainability

Economic Policy Uncertainty (EPU), introduced by Baker et al. (2016), has become a major area of research due to its wide implications for global economic stability and development (Jing et al., 2023; Li & Huang, 2021; Tabash et al., 2023). These studies generally indicate that EPU serves to create caution in decision-making that may undermine investment, obstruct economic growth, and destabilize financial markets. EPU may also affect environmental sustainability by altering green investments, environmental regulations, economic versus environmental trade-offs, and resource use. Therefore, recent studies have given more attention to the potential impact of EPU on environmental sustainability (Chu et al., 2023; Huang et al., 2023; Khan et al., 2022; Pirgaip and Dinçergök 2020). However, empirical findings in this emerging body of

research are scattered and inconsistent due to the complexities and multidimensionality of the relationship between EPU and environmental outcomes. According to Jiang et al.(2019), theoretically, EPU can affect environmental sustainability in two ways: direct policy adjustments and indirect effects on economic demand. Direct policy adjustments occur when high EPU reduces the government's commitment to environmental policies. This reduction leads to weaker enforcement and compliance, thus undermine the efforts to promote sustainability. On the other hand, the indirect effect arises when EPU disrupts economic conditions, causing a decline in investments and changes in demand for sustainable technologies and practices. These economic disruptions further hinder progress toward achieving environmental sustainability.

Wang et al. (2020) also extended this theory by introducing investment and consumption channels to explain the theoretical relationship between EPU and environmental sustainability. According to the investment channel, high EPU discourages green energy investments and leads companies to shift to carbon-intensive methods (Yu et al., 2021; Zhou et al., 2024). This is because EPU can delay environmentally friendly projects (Trinh, 2024) and potentially increase unsustainable investments (Kong et al., 2022). Thus, environmental sustainability goes down with the high EPU. However, the consumption channel argues that high EPU lowers energy use and that of energy-intensive goods, as businesses and consumers substitute precautionary behaviors (Wang et al., 2020). This implies that environmental sustainability will increase as the EPU increases. As such, the overall effect of EPU on sustainability is derived from the two offsetting channels.

Previous empirical works on this link have also produced inconsistent findings. Some literature claims that high EPU undermines environmental protection. For example, Nakhli et al. (2022) study used a bootstrap rolling approach to examine the relationship between EPU and environmental sustainability in the USA. The study used monthly data from 1985 to 2020 and carbon emissions as environmental sustainability indicators. The estimated result showed that higher EPU is associated with higher dependence on nonrenewable energy in the USA. In turn, the dependency worsens carbon emissions and the USA's carbon neutrality goal. This finding was also supported by Farooq et al. (2023) who discovered that high EPU leads to CO₂ emissions in China in both the long and short run. Using time series data from 1990 to 2018 in another study for Egypt, Selmei and Elamer (2023) analyze the effects of EPU

on environmental sustainability. The findings revealed that a 1% increase in EPU leads to a 5% rise in carbon emission intensity in the long run and a 0.58% increase in the short run. They argue that EPU creates a business environment that promotes energy-intensive industries while deterring investments in clean energy technologies, thus exacerbating environmental challenges.

Huang et al. (2023), reviewed the global relationship between EPU and greenhouse gas emissions using the “Panel Corrected Standard Errors (PCSE)” and “Generalized Least Squares (GLS)” methods. They examined data from 19 developed and developing countries between 2001 and 2019. The study results suggest that EPU generates higher GHG emissions by blocking investments in renewable energy and low-carbon technologies in the studied area. The effect is especially severe in developing countries with low carbonates because it prevents the transition to renewable energy and environmental conservation. This finding was further supported by Iqbal et al. (2022), who demonstrated that EPU extensively increases CO₂ emissions in the short and long run for both developed and developing countries. The authors also claim that political stability can lower the EPU effect in some countries. In another study, Syed & Bouri (2022) show that the impacts of EPU on United States CO₂ emissions differ over time. They found that in the short run, EPU raises emissions by discouraging innovation, R&D, and technological advancement. This shift also shifts policymakers’ focus away from the environment and toward focus on economic policy issues. However, in the long run, their research indicates that EPU cuts emissions and promotes environmental sustainability. The authors also argue that the extended economic slowdown resulting from heightened uncertainty prevents investment and consumption in energy-intensive sectors. Therefore, it reduces emissions in the long run.

On the other hand, Anser et al. (2021) in their analysis of the top ten carbon-emitting countries obtained a different pattern from 1990 to 2015. They find that EPU decreases CO₂ emissions in the short run due to reduced energy consumption and economic activity during elevated uncertainty. However, in the long run, they find a positive relationship in which EPU leads to higher emissions. The reasons behind this are decreased investment in R&D, innovation, and renewable energy to maintain the need for using older, more polluting technologies. Moreover, Anser et al. (2021) show that the drivers of emissions exhibit a temporal shift as the source of emissions rapidly shifts from consumption in the short term to investment in the long term. On the other

hand, Abbasi & Adedoyin (2021) also found a positive but statistically insignificant relationship between EPU and environmental sustainability in China. This outcome was attributed to firms' sustainability policies, which may reduce EPU's negative environmental impact.

In another study, Zhang et al.(2022), demonstrate that EPU does not symmetrically affect the environmental sustainability of the USA and China. However, they found asymmetrical effects. The authors find that a reduction in ecological sustainability results from a decrease in EPU in the U.S. According to the author, the reason is that enterprises start to make investments and production, and consumers' demand increases, which requires more energy consumption and carbon emissions. On the other hand, in the U.S., a positive change in EPU has no significant effects on the environment. While they do so in China, the authors argue that positive change in EPU worsens environmental sustainability in the long run. According to the author, such an effect is due to stagnation in research and development and innovation and favoring high-energy, low-cost production modes.

In Europe, Javed et al. (2023) employed linear and nonlinear autoregressive distributed lag (ARDL) approaches to examine the short and long-run impact of EPU on environmental sustainability in Italy. The linear results revealed that while EPU helps to improve environmental sustainability in the long run, it exacerbates it in the short run. However, the nonlinear results show that EPU worsens environmental sustainability in the short and long run. In recent studies, Bergougui et al. (2024), examined the asymmetric relationship between EPU and environmental sustainability in Algeria. The result shows that positive shocks to EPU enhance environmental sustainability in Algeria. However, negative shocks do not have a similarly positive effect. Also, the author argues that the impact of EPU on improving environmental sustainability is more substantial during times of increasing uncertainty.

While many previous studies have focused on the impact of EPU on environmental sustainability by examining its effects on carbon emissions, recent research has expanded the scope to include its broader implications for ecological footprint consumption. In this regard, Esmaili et al.(2023) examined the effects of EPU on the ecological footprint (ECOF) of 19 energy-intensive countries from 1978 to 2018. Using ARDL and CS-ARDL approaches, the authors conclude that while EPU increases ecological footprint in the short run, it also has a negative effect in the long run.

Similarly, Anser et al. (2021) investigated the impact of EPU on the ecological footprint of certain emerging economies, including Brazil, Mexico, Russia, Colombia, and China, from 1995 to 2015. Their result revealed that EPU is a driving force behind the escalation of the ecological footprint in these economies. The authors further argue that the effect of investment exceeds that of consumption. Hussain et al. (2022) support this finding for BRICS countries (Brazil, China, Russia, and South Africa) from 1992 to 2020. In contrast, Chu and Le (2022) found a negative impact of EPU on the Ecological Footprint in G7 nations from 1997 to 2015. The authors conclude that EPU discourages both production and consumption activities of these regions, leading to economic contraction. This, in turn, results in lower energy consumption and a reduced ecological footprint, ultimately improving environmental sustainability.

Regarding asymmetry, Oryani et al. (2022) discovered that EPU's asymmetric impact on the ecological footprint exists in South Korea. Specifically, they conclude that a positive shock in EPU tends to increase the Long-term Emission Factor (LEF) in the long run but decreases it in the short term. However, the influence of the positive shock surpasses that of the negative shock.

In general, the relationship between EPU and environmental sustainability remains uncertain. Some studies suggest that EPU negatively impacts sustainability, while others suggest positive effects. Also, some research shows asymmetrical impacts of EPU on environmental sustainability in the short and long term, while others do not. Moreover, most previous studies focus on CO₂ emissions and do not explore how EPU affects the ecological footprint. Therefore, further research is warranted to address these gaps.

4.2.2 Oil price and environmental sustainability

Since Hamilton (1983) highlighted a significant relationship between oil prices and economic growth in the US, the role of oil in influencing economic activities has received considerable attention in the literature. Subsequent research has also further explored how fluctuations in oil prices significantly impact macroeconomic indicators by affecting economic activity (Hassan, 2021; Lardic and Mignon, 2006; Xiuzhen et al., 2022). Additionally, recent studies have begun to examine the impact of oil price changes on the environment. However, these studies focus on indirect impacts through exploring the relationship between oil prices, economic growth, and energy consumption (Deyshappriya et al., 2023; Miamo and Achuo, 2021). While a few

studies have directly examined the relationship between oil prices and environmental sustainability (Achuo, 2022; Agbanike et al., 2019; Joof et al., 2023), there is a lack of consensus among these studies.

The theoretical effect of oil price shock on environmental sustainability can be explained through factor substitution and technological innovation. Assuming other factors remain constant in the short run, an increase in oil prices will lead to a higher unit cost of production for the companies. As a result, they may opt for cleaner energy sources or invest in technologies that reduce energy consumption to sustain business. With this transition, there will be less energy consumption and less emission of greenhouse gases. Therefore, environmental sustainability will be improved. On top of that, oil price shock could also lead to a decrease in carbon emissions and ecological impact via decreasing consumption demand or shifting consumption patterns (Abumunshar et al., 2020; Xueqin Dong et al., 2024). This supports neoclassical economics theory, which says that a change in the price of a given commodity with its close substitutes will negatively affect the demand for such goods.

The negative effect of oil prices on carbon emissions and ecological footprint has been also shown by empirical studies. For example, Abumunshar et al. (2020) have found that oil prices rising in Türkiye have reduced carbon emissions. The authors argue that higher oil prices motivate energy efficiency and encourage the use of cleaner energy sources, leading to lower emissions in the country. This implies that high oil prices could help increase environmental sustainability. However, the authors emphasize the importance of institutionally robust ecological policies so that these efforts lead to environmental improvements. According to Akadiri & Adebayo (2022), the pressure of the increase in oil prices will push the development of technologies that significantly reduce energy consumption efficiency and decrease carbon emissions. The main argument of this study is that oil plays vital in socio-economic variables for the development of energy policies, especially in developing economies.

In another study, Rasheed et al. (2022) investigated the long-run interrelationships between energy consumption, oil price, and carbon dioxide emission in 30 European countries during the period of 1997–2017. The estimated results show that emissions are inversely related to the oil price for the indicated periods. According to the study, soaring oil prices trigger a move to cleaner energy sources and release less carbon into the atmosphere. Also, this argument was consistent with the work of Zaghdoudi (2017) in OECD countries who argue that the cause of this phenomenon can be the

ability of the oil-exporting states to reinvest their revenues into renewable energy projects. In their case, Li et al. (2020), and Mensah et al. (2019), also found that increased oil prices result in lower oil consumption and lower carbon emissions in China and Africa.

In BRICS countries, Dong et al. (2024) investigated the relationship between oil prices and ecological footprints. Their findings using the “Cross-Sectional Autoregressive Distributed Lag (CS-ARDL)” estimator showed that oil prices harm ecological footprints. Furthermore, they noticed that a higher crude oil price is associated with decreased ecological footprints caused by reduced energy demand. Saboori et al. (2016) support this perspective by a study on OPEC countries from 1977 to 2008. The author found that higher oil prices resulted in less environmental damage, with a lower ecological footprint. The author also discusses how these countries need to decrease their dependence on fossil fuels. In addition, the author also suggests that labor and capital should be reallocated to renewable energy development with improvements in energy efficiency and promoting energy-saving practices. These studies together show that rises in oil prices encourage green economic development in terms of lowering CO₂ emissions and smaller ecological footprints.

On the other hand, the previous studies put forward that oil prices can have a negative effect on environmental sustainability (Achuo, 2022). For instance, Johnsson et al. (2019) pose that the wide availability of fossil fuels is an important threat to climate change mitigation and other environmental problems. This is especially true in the areas whose major source of income comes from oil due to greater extraction caused by the price volatility of oil (Baffes et al., 2015). Al-Maamary et al. (2017) show in the Gulf Cooperation Council (GCC) countries that oil price fluctuations make renewable energy projects unviable, thereby reinforcing the reliance on environmentally damaging fossil fuels. Hasan et al. (2024) also conducted another study on major oil consuming countries. The authors found a positive correlation between oil prices, ecological footprints and carbon emissions. The study outcome reveals that oil consumption aggravates environmental degradation, quickens climate change, escalates energy insecurity and exacerbates health risks, and impedes the shift to sustainable energy sources.

Using nonlinear ARDL estimators, Malik et al. (2020) studied the asymmetric effects of oil price changes on carbon emissions in Pakistan from 1971–2014. According to their estimated result, oil price shocks do not equally affect all sectors. Instead, the

response depends on the degree of oil dependency for energy, the flexibility of energy demand, and the availability of alternative energy sources. The study concluded that carbon emissions will fall as consumers and producers implement energy-saving measures to cut costs when positive changes in oil prices rise. Nevertheless, when negative changes occur, emissions rise as people do more carbon-intensive things, and the cost is lower. Sector responsiveness to these changes is a function of their reliance on oil and their access to substitutes.

Also, the effect of oil prices on CO₂ emissions in Gulf Cooperation Council (GCC) countries during the period 1980–2019 were investigated by Mahmood et al. (2022). The analysis revealed that rising oil prices contribute to higher CO₂ emissions in Oman, Qatar, and Saudi Arabia, indicating a scale effect. However, increased oil prices in Kuwait and the UAE were associated with lower CO₂ emissions, suggesting technique and composition effects. Furthermore, the study found that declining oil prices lead to higher CO₂ emissions in Bahrain but result in reduced emissions in Kuwait and the UAE. The author argues that in these countries, the impact of negative oil shocks is significantly greater than that of positive shocks in promoting green technologies. In contrast, Ebaid et al. (2022) found that positive oil price shocks between 1996 and 2016 reduced CO₂ emissions and supported environmental sustainability in these countries, while negative shocks showed no significant effects. Another study by Mujtaba and Jena (2021) and Mahmood et al. (2020) analyzed the impact of oil prices in India and Saudi Arabia. Interestingly, their findings indicate that rising and falling oil prices contribute positively to carbon emissions in the country. They argue that rising oil prices stimulate economic activity in carbon-intensive industries, thereby increasing emissions. However, falling oil prices reduce the cost of energy, encouraging greater consumption of fossil fuels, which also results in higher carbon emissions. For Africa, Hassan and Mhlanga (2023) found that positive changes in oil prices are linked to a larger ecological footprint in African oil-producing countries. In contrast, negative changes are associated with a smaller footprint.

From the reviewed literature, we conclude that scholars have no consensus regarding the effects of crude oil price changes on environmental sustainability, particularly concerning the nature of the relationship between these variables. Furthermore, there is limited attention to regional disparities, especially in sub-Saharan Africa, where diverse economic structures and varying levels of oil dependency create unique challenges. Most studies focus on long-term impacts, often neglecting the short-term

dynamics of oil price shocks. Additionally, the asymmetrical effects of positive and negative oil price changes on emissions and ecological sustainability in SSA remain underexplored, emphasizing the need for more region-specific research.

4.2.3 Fdi and environmental sustainability

The relationship between FDI and environmental sustainability has been extensively studied. Recently, this topic has also attracted significant attention in the literature (e.g., Al-Nimer et al., 2022; Duodu et al., 2021; Shahbaz et al., 2018; Tsoy and Heshmati, 2023). However, its impact on environmental sustainability in host countries remains a subject of ongoing debate and is inconclusive.

In theory, the effect of FDI environmental sustainability depends on two hypotheses: "the pollution haven hypothesis (PHH) and the pollution halo hypothesis (PH)." PHH argues that foreign firms may relocate their polluting industries to countries with less stringent environmental regulations to reduce production costs, particularly in developing countries. Several empirical literature also align with this hypothesis (eg. Nguyen-Thanh et al., 2022; Qamri et al., 2022; Singhania & Saini, 2021). For instance, Bouchoucha (2024) examined the relationship between FDI and environmental sustainability in the "Middle Eastern and North African" (MENA) region. The author found that FDI negatively impacts environmental sustainability by increasing carbon emissions. Meanwhile, Asongu and Odhiambo (2021) performed a similar analysis in SSA and found a negative effect of FDI on environmental sustainability in the region.

Wang & Uctum (2024) demonstrated that FDI can worsen environmental sustainability in low-income countries through enhancing ecological footprint consumption. Similarly, Doytch (2020) arrived at a similar conclusion for low- and middle-income countries, emphasizing that these nations face ecological challenges primarily through production-related impacts. Emmanuel et al. (2023), in an analysis of 101 countries from 1995 to 2017, highlighted the critical role of FDI in influencing ecological footprint consumption. Their findings argue that while FDI might yield short-term environmental improvements, it often leads to long-term environmental degradation, thus emphasizing the temporal sensitivity of its effects. However, other studies have found either a neutral impact of FDI on the environment or insufficient information to confirm the PHH (Javorcik and Wei, 2003; Ssali et al., 2019).

On the other hand PH claims that the FDI contribute positively to environmental sustainability by transferring technologies and practices cleaner from developed countries, potentially improving the conservation of energy and reducing emissions (Z. Chen et al., 2022). The effect of the PH can manifest itself through the influx of FDI that gives priority to sustainable practices and advanced technologies. While developed nations companies invest in emerging markets, they can introduce innovations that promote energy efficiency and the lowest levels of emission. Studies indicate that these investments can basically contribute to better environmental management and compliance with higher ecological standards in the host nations (Abbass et al., 2022; P. Liu et al., 2024).

Evidence that supports the halo effect of pollution are observed in several studies. For example, Liu et al.(2024) explored the impact of Chinese FDI on CO₂ emissions on the countries of the belt and road initiative, identifying positive effects on energy efficiency resulting from technological exchanges. Similarly, Wang et al. (2019) evaluated Beijing's investments in their neighboring countries and found significant reductions in pollution related to fdi entries, emphasizing the role of technology transfer and increasing environmental awareness among local companies.

Fang et al. (2023) show that foreign direct investment (FDI) can help lower urban pollution in Chinese cities by encouraging cleaner production methods. However, they point out that good management of FDI and strong export capacity are important for these positive effects to happen. Bénassy-Quéré et al. (2007) indicate that multinationals can indeed provide advanced technologies and practices that improve environmental performance when they establish operations in developing countries. This observation is aligned with the hypothesis of the pollution halo, which suggests that the investment of countries with strict environmental regulations can lead to an improvement in local environmental standards.

Recently, Roy (2024) studied the effect of FDI on India's ecological footprint using data from 1990 to 2016. Employing the autoregressive distributed lag (ARDL) technique, the author found a negative relationship between FDI and ecological footprint, providing evidence supporting the PH. In Sub-Saharan Africa, Duodu et al. (2021) used the "System Generalized Method of Moments (GMM)" to analyze FDI's impact on environmental sustainability from 2005 to 2019. The aauthor conclude that

while FDI enhances environmental sustainability in the long run, it also has adverse effects in the short run.

On the contrary, other studies have come out with inconclusive results. For instance, Adeel-Farooq et al. (2021), assert that the environmental policy of the source country is more important in predicting the sign of the relationship between FDI and environmental performance than the policy environment of the host country. According to Wang et al. (2021), FDI impacts positively on ecological quality. Nevertheless, this impact varied with absorptive capacity in the recipient country. Shahbaz et al. (2015), argue that the effect of FDI inflows on environmental sustainability depends on the difference in the national income. On the contrary, Mahadevan and Sun (2020) discovered that FDI does not affect environmental sustainability.

In most previous studies, a linear relationship was assumed, while recent studies have investigated the nonlinear (asymmetric) relationship between FDI and environmental sustainability (Abdul-Mumuni et al., 2022; Guoyan et al., 2022; Hassan Jakada and Mahmood, 2020). For instance, Abdul-Mumuni et al. (2022) and Hassan Jakada and Mahmood (2020) discovered evidence of asymmetric effects of FDI on environmental sustainability in SSA countries, including Nigeria. Their findings indicate that positive FDI shocks reduce environmental sustainability, while negative shocks increase environmental sustainability in the region. The asymmetric pattern is not unique to SSA. However, this asymmetric effect is also supported by global studies such as by Zhao and Peng (2024) in developed and developing countries, Tran et al. (2024) in Indonesia, and Kanwal et al. (2023) in Pakistan.

Therefore, whether FDI inflow decreases or increases environmental suitability is inconclusive in previous studies. Some studies present evidence to support the PHH, while others offer support for PH hypothesis. Also, while some studies argue that the relationships between FDI and environmental suitability are linear, others found a nonlinear relationship. These results from earlier studies are likely to depend on several factors that may involve the level of environmental regulation and technology transfer and the absorptive capacity of the host country. Also, most of them have used linear specifications for the FDI variable, except for the nonlinear studies by Hassan Jakada and Mahmood (2020) and Abdul-Mumuni et al. (2022) for the Nigeria and SSA countries, respectively. Moreover, apart from Roy(2024), which used ecological

footprint as an environmental suitability indicator, most of the panel studies, including studies focusing on SSA, have used carbon emissions as a proxy variable for environmental suitability that might need further investigation.

4.3 Methodology

4.3.1 Data

This study considers economic policy uncertainty (EPU), oil prices, foreign direct investment (FDI), gross domestic product (GDP), renewable energy, and population as determinants of environmental sustainability. The analysis is based on annual data from 1991 to 2023 and focuses on the top ten emitters in Sub-Saharan Africa (SSA). These countries include Angola, Kenya, Ethiopia, Côte d'Ivoire, Ghana, Nigeria, South Africa, Senegal, Sudan, and Tanzania. The selection of the period and the countries were determined by data availability and their significant contribution to the region's environmental and economic activities. For instance, in 2023, these countries accounted for 85% of emissions, 65% of the population, and 85% of the region's GDP. Therefore, focusing on these countries ensures that our study captures a significant portion of the region's environmental impact, maintains data consistency, and allows for a detailed and focused analysis.

Environmental sustainability is assessed using two indicators: carbon dioxide emissions (CO₂) and ecological footprint consumption (ECOF). CO₂ data is obtained from the World Development Indicators (WDI), while ECOF data is sourced from the Global Footprint Network. EPU is measured using the World Uncertainty Index (WUI) developed by Ahir et al. (2024). The index is constructed from Economist Intelligence Unit (EIU) country reports and provides quarterly EPU values, averaged annually for this study. Higher WUI values indicate higher uncertainty.

Besides, Oil prices are measured using the global benchmarks Brent (BR) and West Texas Intermediate (WTI) crude oil. Data for these variables is sourced from the U.S. Energy Information Administration (EIA). These benchmarks are used for two reasons: first, they are prominent within the international oil market. Second, the countries analyzed in this study lack sufficient data on domestic oil prices. Also, FDI is expressed as the ratio of net inward FDI to GDP, and renewable energy is calculated as a percentage of total final energy consumption. FDI, GDP, renewable energy, and

population data are sourced from the WDI. To address potential biases arising from scale differences, EPU, FDI, and GDP growth rate data were not transformed into logarithms. However, logarithmic transformations were applied to all other variables. Detailed information on the variables, including their symbols, measurements, and sources, is presented in (Table 4.1).

Table 4.1: Variables, symbols, measurements, and sources.

Variables	Symbol	Measurement	Source
Carbon dioxide emissions	CO ₂	kilo Tone	WDI
Ecological footprints	ECOF	Global Hectare	Global footprint network
Economic policy uncertainty	EUP	Index	https://www.policyuncertainty.com/wui_quarterly.html
Brent Crude	BR	USD	US EIA
West Texas Intermediate	WT	USD	US EIA
Forign direct investemnt	FDI	% of GDP	WDI
Economic growth	GDP	Annual growth rate	WDI
Renewable energy	REN	% of energy consumption	WDI
Population	POP	Millions	WDI

4.3.2 Model specification

Following the study of Esmaeili et al. (2023), Hassan and Mhlanga (2023), and Maji et al. (2017), we propose the following model to empirically examine the relationship between EUP, oil price shocks, FDI, control variables, and environmental sustainability in Sub-Saharan Africa (SSA):

$$ENS_{it} = \alpha_i + \vartheta_{it} + \beta_{1i}EPU_{it} + \beta_{2i}OIL_{it} + \beta_{3i}FDI_{it} + \beta_{4i}GDP_{it} + \beta_{5i}REN_{it} + \beta_{6i}POP_{it} + \mu_{it} \quad (4.1)$$

Where: ENS_{it} denotes environmental sustainability; EPU_{it} signifies the economic policy uncertainty index; OIL_{it} represents crude oil price shock; FDI_{it} shows foreign

direct investment; GDP_{it} denotes economic growth; REN_{it} presents energy consumption; POP_{it} stands for population and μ_{it} represent error term.

4.3.3 Estimation technique

4.3.3.1 Ardl approach

The 1992 Rio conference emphasized the importance of adopting sustainable and long-term emission reduction strategies for achieving environmental sustainability. However, countries' short-run progress toward environmental sustainability often varies due to differing economic, social, and policy factors (Abid, 2016; Benlemlih et al., 2022; Chu and Le, 2022). Therefore, an appropriate estimation technique is required to capture both these short-run divergence and long-run homogeneities. In this regard, pooled ordinary least squares (OLS), fixed effects, and random effects models are inadequate as they fail to account for both short-run divergence and long-run homogeneity.

Additionally, the traditional “Autoregressive Distributed Lag (ARDL)” model, introduced by Pesaran (1998) accommodates both short-run dynamics and long-run equilibrium relationships. However, it is typically designed for single time-series data and may yield biased or inconsistent estimates when applied to panel data with significant heterogeneity across groups. This limitation arises because the traditional ARDL model does not explicitly account for cross-sectional dependence or variations in slope coefficients among entities, which are critical in panel data analysis.

However, the panel ARDL model proposed by Pesaran and Smith (1995) and extended by Pesaran et al. (1999), offers a promising solution. The panel ARDL model accommodates short-run dynamics specific to each country while preserving long-run homogeneity across groups. Additionally, it effectively addresses issues of endogeneity bias and serial correlation by incorporating adequate lags of both the independent and dependent variables. Furthermore, it allows for the inclusion of variables with integration orders $l(0)$ and $l(1)$. The panel ARDL (p, q, q, \dots, q) specification used in this study is expressed as follows:

$$X_{it} = \sum_{j=1}^p \tau_{ij} X_{i,t-j} + \sum_{j=1}^q \vartheta_{ij} Z_{i,t-j} + \mu_i + \varepsilon_{it} \quad (4.2)$$

Where, X_{it} represents the dependent variable for group i at time t . τ_{ij} are scalars representing the coefficients of the lagged dependent variables X_{it} . $Z_{i,t-j}$ is a $k \times 1$ vector of explanatory variables for group i . v_{ij} are the $k \times 1$ vector of coefficients. i denotes the groups ($i = 1, 2, \dots, N$) and t represents time periods ($t = 1, 2, \dots, T$), μ_i denotes the fixed effects specific to group i and ε_{it} is the error term.

The error correction (ECM) model of equation (4.2) can be written as follows:

$$\Delta X_{it} = (\delta_i X_{i,t-1} + \gamma_i' Z_{i,t}) + \sum_{j=1}^{p-1} \tau_{ij}^* X_{i,t-j} + \sum_{j=0}^{q-1} v_{ij}^* Z_{i,t-j} + \mu_i + \varepsilon_{it} \quad (4.3)$$

Where; $\Delta X_{it} = X_{it} - X_{i,t-1}$ represents the first difference of the dependent variable; X_{it} ; δ_i is the speed of adjustment, expected to be negative and between 0 and -1. A value of 0 indicates no adjustment, while -1 indicates immediate adjustment to long-run equilibrium; $(\delta_i X_{i,t-1} + \gamma_i' Z_{i,t}) + \sum_{j=1}^{p-1}$ is the error correction term (ECT), capturing the long run relationship and $\sum_{j=1}^{p-1} \lambda_{ij}^* X_{i,t-j} + \sum_{j=0}^{q-1} \sigma_{ij}^* Z_{i,t-j} + \mu_i$ represents the short-run model.

Therefore, the panel-ARDL model of the relationship between EPU, OIL price, FDI and environmental quality are:

$$\Delta ENS_{it} = \text{and} \delta_i (ENS_{i,t-1} + EUP_{i,t-1} + OIL_{i,t-1} + FDI_{i,t-1} + \gamma_i' Z_{i,t}) + \sum_{j=1}^{p-1} \tau_{ij}^* ENS_{i,t-j} + \sum_{j=1}^{p-1} \delta_{ij}^* EUP_{i,t-j} + \sum_{j=1}^{p-1} \delta_{ij}^* OIL_{i,t-j} + \sum_{j=1}^{p-1} \delta_{ij}^* FDI_{i,t-j} + \sum_{j=0}^{q-1} v_{ij}^* Z_{i,t-j} + \mu_i + \varepsilon_{it} \quad (4.4)$$

and

The final empirical model, re-parameterized into an error-correction equation and control variable is given by:

$$\begin{aligned}
\Delta ENS_{it} = & \alpha_{1j} + \sum_{n=1}^{k-1} \vartheta_{11in} \Delta \ln ENS_{it-n} + \sum_{n=1}^{k-1} \vartheta_{12in} \Delta EPU_{it-n} + \sum_{n=1}^{k-1} \vartheta_{13in} \Delta \ln OIL_{it-n} \\
& + \sum_{n=1}^{k-1} \vartheta_{14in} \Delta FDI_{it-n} + \sum_{n=1}^{k-1} \vartheta_{15in} \Delta IGDG_{it-n} + \sum_{n=1}^{k-1} \vartheta_{16in} \Delta \ln REN_{it-n} \\
& + \sum_{n=1}^{k-1} \vartheta_{17in} \Delta \ln POP_{it-n} + \vartheta_{1i} ECT_{1it-1} + \mu_i
\end{aligned} \tag{4.5}$$

Where, Δ is operator k is the lag length.

4.3.3.2 Nardl approach

The panel ARDL estimator specified in Equation (4.5) is appropriate for analyzing the effects of EPU, oil prices, and FDI on environmental sustainability. It captures both short-run dynamics and long-run equilibrium relationships while accommodating integrated variables $l(0)$ and $l(1)$. However, a significant limitation of this estimator is its inherent assumption of a symmetric (linear) relationship between the explanatory variables and the dependent variable. This assumption implies that increases and decreases in explanatory variables have proportional and identical effects on independent variables.

However, this assumption neglects the potential for nonlinear or asymmetric effects, often observed in environmental and economic systems. For instance, Falk (1986) suggests that many macroeconomic variables show non-linear properties. This implies that changes in EPU, oil prices, and FDI might lead to asymmetric impacts on environmental sustainability. This is true as an increase in oil prices might lead to a significant improvement in environmental performance due to the adoption of cleaner energy sources, while a decrease might have a negative or delayed effect (Chaudhry et al., 2020; Okwanya et al., 2023). Also, positive and negative changes in FDI or EPU could influence environmental outcomes differently due to structural, economic, or policy-related factors (Demena and Afesorgbor, 2020; Huang et al., 2023). To address these asymmetries, we also employ the nonlinear ARDL (NARDL) model specifically designed to capture asymmetric relationships between variables.

To develop the NARDL model, we adopt the decomposition methodology introduced by Granger and Yoon (2002). This approach involves breaking down the explanatory variables into positive and negative partial sums to capture asymmetric effects. It is

widely applied in empirical research (e.g., Hassan and Mhlanga, 2023; Malik et al., 2020; Shin et al., 2014) and enables us to analyze the distinct effects of increases and decreases in EPU, oil prices, and FDI on environmental sustainability, enhancing the model's ability to capture complex relationships. This decomposition is carried out as follows:

$$EPU_{i,t}^+ = \sum_{j=1}^t \Delta EPU_{i,j}^+ = \sum_{j=1}^t \max(\Delta EPU_{i,j}^+, 0) \quad (4.6)$$

$$EPU_{i,t}^- = \sum_{j=1}^t \Delta EPU_{i,j}^- = \sum_{j=1}^t \min(\Delta EPU_{i,j}^-, 0) \quad (4.7)$$

$$OIL_{i,t}^+ = \sum_{j=1}^t \Delta OIL_{i,j}^+ = \sum_{j=1}^t \max(\Delta OIL_{i,j}^+, 0) \quad (4.8)$$

$$OIL_{i,t}^- = \sum_{j=1}^t \Delta OIL_{i,j}^- = \sum_{j=1}^t \min(\Delta OIL_{i,j}^-, 0) \quad (4.9)$$

$$FDI_{i,t}^+ = \sum_{j=1}^t \Delta FDI_{i,j}^+ = \sum_{j=1}^t \max(\Delta FDI_{i,j}^+, 0) \quad (4.10)$$

$$FDI_{i,t}^- = \sum_{j=1}^t \Delta FDI_{i,j}^- = \sum_{j=1}^t \min(\Delta FDI_{i,j}^-, 0) \quad (4.11)$$

Therefore, following Hassan and Mhlanga (2023), the empirical asymmetric model capturing the relationship between EPU, OIL, FDI, and environmental sustainability is specified as follows:

$$\begin{aligned}
\Delta ENS_{it} = & \text{and} \delta_i (ENS_{i,t-1} + EPU_{i,t-1}^+ + EPU_{i,t-1}^- + OIL_{i,t-1}^+ + OIL_{i,t-1}^- + FDI_{i,t-1}^+ + FDI_{i,t-1}^- \\
& + \sum_{j=1}^{p-1} \tau_{ij}^* ENS_{i,t-j} + \sum_{j=1}^{p-1} \delta_{ij}^* EPU_{i,t-j}^+ + \sum_{j=1}^{p-1} \delta_{ij}^* EPU_{i,t-j}^- + \sum_{j=1}^{p-1} \delta_{ij}^* OIL_{i,t-j}^+ \\
& + \sum_{j=1}^{p-1} \delta_{ij}^* OIL_{i,t-j}^- + \sum_{j=1}^{p-1} \delta_{ij}^* FDI_{i,t-j}^+ + \sum_{j=1}^{p-1} \delta_{ij}^* FDI_{i,t-j}^- + \sum_{j=0}^{q-1} \nu_{ij}^* Z_{i,t-j} \\
& + \mu_i + \varepsilon_{it}
\end{aligned} \tag{4.12}$$

Where, $EPU_{i,t-1}^+$, $EPU_{i,t-1}^-$, $OIL_{i,t-1}^+$, $OIL_{i,t-1}^-$, $FDI_{i,t-1}^+$ and $FDI_{i,t-1}^-$ are the lagged values of EPU, OIL, and FDI, decomposed into positive and negative changes, respectively, for group i at time $t - 1$.

However, the Pesaran and Smith (1995) and Pesaran et al. (1999) panel ARDL model is reliant on three estimators: “Mean Group (MG), Pooled Mean Group (PMG), and Dynamic Fixed Effects (DFE).” The MG estimator performs country-specific regressions, allowing short and long-run heterogeneity (Pesaran and Smith, 1995). The PMG estimator allows short-run heterogeneity but assumes long-run homogeneity (Pesaran et al., 1999). PMG combines pooling and averaging, while MG averages coefficients from separate time series regressions. DFE, in contrast, argues for the homogeneity of all variables and coefficients across all countries in terms of both short-run and long-run estimation (Anser et al., 2021). Therefore, we used the Hausman (1978) specification test to select the best estimator for our study. This test enables us to compare the consistency and efficiency of MG, PMG, and DFE estimators and allows us to choose the optimal estimators.

4.3.3.3 Cross-sectional dependence test

The literature on panel data highlights the presence of interdependence between cross-sectional units. These interdependencies may be from shared shocks, common factors, and systemic relationships. In our case, this is evident through shared economic shocks such as global oil price fluctuations, regional policy uncertainties, and FDI inflows influenced by external factors. These interdependencies significantly affect the transmission of economic and environmental impacts across sample countries. Thus, ignoring such interdependencies often leads to biased conclusion (Hassan and Mhlanga, 2023). In this study, we employed the CD test introduced by Pesaran (2015). The test is robust for the detection and handling of CDs. The null hypothesis of the test is that variables are cross-sectionally independent. The equation for the CD test is as

follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{n-1} \sum_{j=i+1}^n \partial_{ij}^t \right) \quad (4.13)$$

Where, T represents the number of periods; N signifies the number of cross-sections; ∂_{ij}^t represents the covariance between errors of cross-sections i and j at time t .

Table 4.2. presents the results of the CD test. The findings reveal that the null hypothesis of no cross-sectional dependence is rejected for all variables. This indicates significant interdependence among the sample countries. Shared environmental policies or regional dynamics may explain this interdependence. Therefore, estimation techniques that accommodate the issue of CD are necessary to ensure accurate and reliable analysis.

Table 4.2: CD test result.

Variables	Test statics	p-value
lnCO ₂	29.812***	0.000
lnECOF	27.709***	0.000
EPU	7.437***	0.000
lnWT	35.420***	0.000
lnBR	38.54***	0.000
FDI	2.650***	0.008
GDP	4.930***	0.000
lnREN	18.67***	0.000
lnPOP	38.30***	0.000

***, explains the level of significance at 1%

4.3.3.4 Slope heterogeneity test

Once the CD is confirmed in a data set, the next step is to analyze slope heterogeneity. Slope heterogeneity is another significant issue in panel data analysis. Ignoring this problem also leads to invalid results. It arises from differences in economic and demographic characteristics across cross-sectional units. The present study utilized the slope heterogeneity test of Hashem Pesaran and Yamagata (2008). The test evaluates if there are significant differences in the regression slopes among groups or observations in the presence of CD. The null hypothesis assumes slope homogeneity

across cross-sectional units, while the alternative hypothesis indicates slope heterogeneity. The test statistics represented as $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ is obtained through the following formula:

$$\tilde{\Delta} = \sqrt{N} \left(\frac{N^{-1}\tilde{S} - K}{\sqrt{2K}} \right) \quad (4.14)$$

$$\tilde{\Delta}_{adj} = \sqrt{N} \left(\frac{N^{-1}\tilde{S} - E(\tilde{Z}_{it})}{\sqrt{\text{var}(\tilde{Z}_{it})}} \right) \quad (4.15)$$

Where, N represents the total number of observations; \tilde{S} refers to the covariance matrix of the estimated coefficients; K denotes the number of regressors; $E(\tilde{Z}_i)$ represents the expected value of the standardized residuals; (\tilde{Z}_i) indicates the variance of the standardized residuals.

The outcome of the slope heterogeneity test is reported in Table 4.3. The findings show that both $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ values were statistically significant at the 1% level for carbon emissions and ecological footprint. This indicates that slope heterogeneity exists in the dataset. Therefore, the effect of the independent variables on carbon emissions and ecological footprint differs among the sample population.

Table 4.3: Slope homogeneity result.

	lnCO ₂		lnECOF	
	Statics	p-value	Statics	
$\tilde{\Delta}$	11.154 ***	0.000	$\tilde{\Delta}$	11.154 ***
$\tilde{\Delta}_{adj}$	12.815***	0.000	$\tilde{\Delta}_{adj}$	12.815***

***, explains the level of significance at 1%

4.3.3.5 Unit-root test

Next, we employed unit root tests to assess the stationarity of the variables. In this study, we used the second generation unit root test of “Cross-Sectionally Augmented Dickey-Fuller (CADF) and Cross-Sectionally Augmented IPS (CIPS)” tests developed by Pesaran (2007). The test is designed to address issues related to CD and slope heterogeneity. The test is also robust against first-generation unit root tests, which may lead to misleading results in the presence of CD and slope heterogeneity (Esmaeili et al., 2023). The tests are performed under the null hypothesis (H_0) of "non-stationarity" against the alternative hypothesis (H_a) of "stationarity." The CADF test statistics are calculated using the following formula:

$$\Delta X_{it} = \alpha_{it} + \beta_i x_{i,t-1} + \beta_i \tilde{x}_{t-1} + \sum_{j=0}^k a_{ij} \Delta \tilde{x}_{t-j} + \sum_{j=1}^k \delta_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \quad (4.16)$$

Here, \tilde{x}_{t-1} refers to the lagged value of the cross-sectional averages, $\Delta x_{i,t-j}$ represents the first differences of each cross-sectional unit.

The CIPS test statistics are then calculated based on the results of the CADF test using the following expression:

$$\mathbf{CIPS} = n^{(-)} \sum_{i=1}^n \mathbf{CADF}i \quad (4.17)$$

Table 4.4 reports the CADF and CIPS test results. Except for the ecological footprint, Brent crude oil, FDI, and renewable energy, all variables show unit root and non-stationarity at their levels, as the null hypothesis is not rejected at a 1% significance level. However, the null hypothesis of a unit root is rejected for all variables at their first differences. This implies that the data is integrated into either $I(0)$ or $I(1)$.

Table 4.4: Unit-root test results.

Variables	CADF		CIPS		Integration
	Level	Δ	Level	Δ	Level
lnCO ₂	-1.858	-2.971****	-2.187	-4.629***	I (1)
lnECOF	-2.357**	-3.390***	-2.843****	-5.125***	I (0)
EPU	-2.106	-3.767**	-3.613***	-6.162***	I (1)
lnWT	0.519	1.024**	0.661	1.877***	I (1)
lnBR	2.610***	2.610***	2.610***	2.610***	I (0)
FDI	-1.656**	-3.188***	-2.534**	-6.046***	I (0)
GDP	-1.488	-3.046***	-2.721	-4.710***	I (1)
lnREN	-3.171***	-4.576***	-5.405***	-6.077***	I (0)
lnPOP	-1.815	-3.614***	-2.838	-5.472***	I (1)

***, explains the level of significance at 1%

4.3.3.6 Co-integration test

When variables are integrated I (0) or I (1), the next stage in the econometric analysis involves the investigation of cointegration. In this study, we used the Westerlund (2007) cointegration test. Unlike the Pedroni (1999) and Kao (1999) tests, the Westerlund test does not rely on typical factor constraints. The test also considers CD and slope heterogeneity (Ansari et al., 2020). The test checks for error correction in series integrated at $I(1)$ or $I(0)$ using two-panel means (P_t and P_a) and two-group means (G_t and G_a) (Khan et al., 2020). The panel means test evaluates whether the entire panel is integrated.

On the other hand, the group means test checks if at least one element is integrated. If the “null hypothesis” is accepted, it indicates no long-term relationship among the variables. However, if the “alternative hypothesis” is accepted, it suggests the presence of long-term cointegration. The following equation can represent the test specifications for Westerlund (2007):

$$\Delta X_{it} = \tau_i' c_t + \delta_i (X_{it-1} - \beta_i' y_{it-1}) + \sum_{j=1}^{p_i} \delta_{ij} \Delta x_{it-j} + \sum_{j=-p_i}^{p_t} \varphi_{ij} \Delta y_{i,t-j} + \varepsilon_{it} \quad (4.18)$$

The t-statistics for the group statistics G_t and G_a are calculated using the following expressions:

$$G_t = \frac{1}{N} \sum_{i=1}^N \frac{\partial_i^!}{SE \partial_i^!} \quad (4.19)$$

$$G_a = \frac{1}{N} \sum_{i=1}^N \frac{T \partial_i^!}{\partial_i^!(1)} \quad (4.20)$$

The t-statistics for panel P_t and P_a are also derived using the following formulas:

$$P_t = \frac{\partial^!}{SE(\partial^!)} \quad (4.21)$$

$$P_a = T \partial^! \quad (4.22)$$

The Westerlund (2007) cointegration test results are shown in Table 4.5. The results indicate a long-term relationship among the variables. The G_t , G_a , and P_t statistics for $\ln CO_2$ and $\ln ECOF$ reject the null hypothesis of no cointegration at a 1% significance level. However, the P_a statistic does not reject the null hypothesis for either $\ln CO_2$ or $\ln ECOF$. Three out of four test statistics (G_t , G_a , and P_t) suggest a long-term relationship among the variables.

Table 4.5: Cointegration test results.

Cointegration	lnCO ₂		lnECOF	
	T statics	p-value	T statics	p-value
Gt	-2.832***	0.002	-3.537***	0.000
Ga	-3.429***	0.003	-1.676**	0.046
Pt	-4.366***	0.000	-3.565***	0.000
Pa	-3.859	0.621	-4.737	0.368

***, ** explains the level of significance at 1% and 5%, respectively

4.4 Results and Discussion

4.4.1 Descriptive statistics

Table 4.6 presents the descriptive statistics for the variables utilized in our study. The data indicate significant variations across the countries examined. South Africa has the highest mean CO₂ emissions at 352,214.3 kilotons, with a standard deviation of 73,568.56, likely attributed to its extensive industrial activities. Regarding the ecological footprint (ECOF), Nigeria leads with the highest mean, signifying considerable resource consumption, while Senegal demonstrates a lower mean, indicating a reduced environmental impact.

South Africa also leads in Economic Policy Uncertainty (EPU), with the highest mean (1.493), whereas Tanzania reports the lowest mean (0.468). Senegal experiences the most volatility in FDI inflows, with a mean of 2.34 and a standard deviation of 2.319, suggesting irregular investment patterns. Conversely, Kenya shows more stable FDI trends, with a mean of 0.78 and a standard deviation of 0.803. The oil price variable remains consistent across all countries, reflecting global market trends rather than country-specific factors.

Regarding renewable energy, Ethiopia stands out with the highest mean (913.875), in contrast to South Africa, which records a much lower mean (110.656). Economic growth also varies significantly, with Ethiopia leading with an impressive mean GDP growth of 6.741%, signaling steady progress, while Angola lags with a mean growth of 3.643%, reflecting greater economic instability. Nigeria has the highest maximum population, at 220 million, while Senegal has the lowest maximum population, at 17 million.

Table 4.6: Descriptive statistics.

Country	Variable	Obs	Mean	SD	Min	Max	Skewness	Kurtosis
Angola	CO ₂	33	18450.12	6432.714	6564	31649	0.051	-0.212
Angola	ECOF	33	20690909	9920445	9800000	40000000	0.452	-1.395
Angola	EPU	33	0.481	0.335	0	1.266	0.508	-0.374
Angola	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Angola	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Angola	FDI	33	3.757	10.379	-10.038	40.167	1.62	3.668
Angola	GDP	33	3.643	7.71	-23.983	15.03	-1.174	3.94
Angola	REN	32	577.625	197.694	49	764	-1.762	2.801
Angola	POP	33	21484848	7254831	12000000	36000000	0.458	-0.967
Ethiopia	CO ₂	33	7795.152	5753.698	1517	18878	0.857	-0.76
Ethiopia	ECOF	33	75696970	16148694	55000000	100000000	0.347	-1.382
Ethiopia	EPU	33	0.768	0.565	0.065	2.501	0.962	1.233
Ethiopia	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Ethiopia	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Ethiopia	FDI	33	2.304	1.8	0	5.576	0.235	-1.189
Ethiopia	GDP	33	6.741	5.626	-8.672	13.573	-1.266	1.245
Ethiopia	REN	32	913.875	151.861	90	975	-5.479	30.611
Ethiopia	POP	33	81878788	22445430	48000000	120000000	0.238	-1.15
Ghana	CO ₂	33	9279.242	5862.669	2257	22125	0.663	-0.673
Ghana	ECOF	33	38272727	14107340	17000000	59000000	0.024	-1.417
Ghana	EPU	33	0.748	0.511	0	1.908	0.987	0.167
Ghana	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Ghana	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Ghana	FDI	33	3.836	2.712	0.251	9.466	0.583	-0.785
Ghana	GDP	33	5.233	2.487	0.514	14.047	1.463	3.972
Ghana	REN	32	551.219	232.068	39	829	-1.034	0.54
Ghana	POP	33	23606061	5639921	15000000	33000000	0.203	-1.26
Kenya	CO ₂	33	11574.06	5205.932	5991	20097	0.548	-1.35
Kenya	ECOF	33	41272727	5912237	33000000	50000000	0.102	-1.631
Kenya	EPU	33	1.017	0.769	0	3.252	0.614	0.506
Kenya	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Kenya	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Kenya	FDI	33	0.78	0.803	0.041	3.095	1.591	1.636
Kenya	GDP	33	3.657	2.314	-0.799	8.058	-0.251	-0.609

Table 4.6 (continued): Descriptive statistics.

Country	Variable	Obs	Mean	SD	Min	Max	Skewness	Kurtosis
Kenya	REN	32	714.438	173.433	69	816	-3.46	11.501
Kenya	POP	33	37696970	9671107	23000000	54000000	0.132	-1.306
Nigeria	CO ₂	33	96127.42	11819.85	72769	119544	0.035	-0.673
Nigeria	ECOF	33	1.48E+08	29426559	93000000	180000000	-0.631	-1.213
Nigeria	EPU	33	0.514	0.412	0	1.547	0.646	-0.206
Nigeria	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Nigeria	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Nigeria	FDI	33	1.319	0.845	-0.04	2.9	0.118	-1.089
Nigeria	GDP	33	4.288	3.958	-2.035	15.329	0.487	0.662
Nigeria	REN	32	748.125	255.538	84	886	-2.334	3.776
Nigeria	POP	33	1.49E+08	37411360	95000000	220000000	0.294	-1.118
Senegal	CO ₂	33	6055.576	2855.107	2326	12298	0.375	-0.921
Senegal	ECOF	33	16000000	3648630	10000000	22000000	0.123	-1.237
Senegal	EPU	33	0.498	0.407	0	1.477	0.845	0.01
Senegal	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Senegal	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Senegal	FDI	33	2.34	2.319	-0.104	9.388	2.067	4.206
Senegal	GDG	33	3.698	2.155	-0.746	7.407	-0.222	-0.803
Senegal	REN	32	414.75	137.249	40	555	-1.784	3.109
Senegal	POP	33	11721212	2927110	7500000	17000000	0.332	-1.136
South Africa	CO ₂	33	352214.3	73568.56	238781	448298	-0.218	-1.566
South Africa	ECOF	33	1.69E+08	29128763	1.2E+08	200000000	-0.43	-1.426
South Africa	EPU	33	1.493	1.364	0.051	5.372	1.44	1.758
South Africa	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
South Africa	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
South Africa	FDI	33	1.411	1.852	-0.06	9.678	3.21	12.557
South Africa	GDP	33	2.06	2.42	-5.963	5.604	-1.204	2.516
South Africa	REN	32	110.656	55.951	8	186	-0.21	-0.823
South Africa	POP	33	50060606	5716967	40000000	60000000	0.096	-1.038
Sudan	ECOF	33	54181818	6789029	42000000	67000000	0.399	-0.588
Sudan	EPU	33	0.591	0.507	0	1.69	0.739	-0.51

Table 4.6 (continued): Descriptive statistics.

Country	Variable	Obs	Mean	SD	Min	Max	Skewness	Kurtosis
Sudan	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Sudan	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Sudan	FDI	33	2.296	1.675	-0.093	6.318	0.331	-0.29
Sudan	GDP	33	2.61	5.759	-17.005	18.313	-0.799	4.266
Sudan	REN	32	668.281	179.179	61	856	-2.387	6.69
Sudan	POP	33	31545455	7770501	21000000	47000000	0.434	-0.912
Tanzania	CO ₂	33	6621.485	4297.919	1860	14961	0.565	-1.078
Tanzania	ECOF	33	14393939	1886455	11000000	16000000	-0.91	-0.762
Tanzania	EPU	33	0.468	0.408	0	1.891	1.928	4.275
Tanzania	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Tanzania	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Tanzania	FDI	33	2.504	1.488	0	5.664	0.292	-0.508
Tanzania	GDP	33	5.098	2.021	0.584	7.672	-0.746	-0.527
Tanzania	REN	32	841.625	204.078	82	952	-3.437	11.395
Tanzania	pop	33	42393939	11680484	26000000	65000000	0.453	-0.942
Côte d'Ivoire	CO ₂	33	6700.485	2701.416	2705	11007	0.21	-1.068
Côte d'Ivoire	ECOF	33	19636364	3887626	12000000	25000000	-0.332	-0.844
Côte d'Ivoire	EPU	33	0.752	0.598	0.07	2.2	0.839	-0.291
Côte d'Ivoire	WT	33	45.811	29.192	10.87	95.99	0.523	-1.092
Côte d'Ivoire	BR	33	51.183	32.356	12.8	111.63	0.576	-0.972
Côte d'Ivoire	FDI	33	1.356	0.651	0.177	3.874	1.759	6.18
Côte d'Ivoire	GDP	33	3.446	4.268	-5.37	10.76	-0.268	-0.832
Côte d'Ivoire	REN	32	644	196.407	64	791	-2.47	5.284
Côte d'Ivoire	POP	33	19515152	4691223	12000000	28000000	0.09	-1.032

4.4.2 Correlation

Figure 4.7 and Table 4.7 present the circular correlation graph and matrix results. The result reveals a strong association between $\ln\text{CO}_2$ and $\ln\text{ECOF}$. This indicates a direct relationship between ecological footprint consumption and CO_2 emissions. Moreover, $\ln\text{WT}$ and $\ln\text{BR}$ display an almost perfect correlation of 0.945, underscoring their interconnectedness as oil price benchmarks. These high correlation values raise potential concerns about multicollinearity when these variables are included in regression models. While both EPU and POP exhibit positive correlations with carbon

emissions $\ln\text{CO}_2$ and $\ln\text{ECOF}$, the variables FDI, GDP, and REN show negative relationships with these measures. Except for FDI, which has an insignificant impact on carbon emissions, all other variables significantly influence both carbon emissions and the ecological footprint. The correlation analysis shows a generally weak linear relationship between the modelled variables. This indicates a low risk of multicollinearity issue in our model. Therefore, the estimated coefficients of our model are likely to have a strong explanatory power, providing reliable insights into the relationships between the variables.

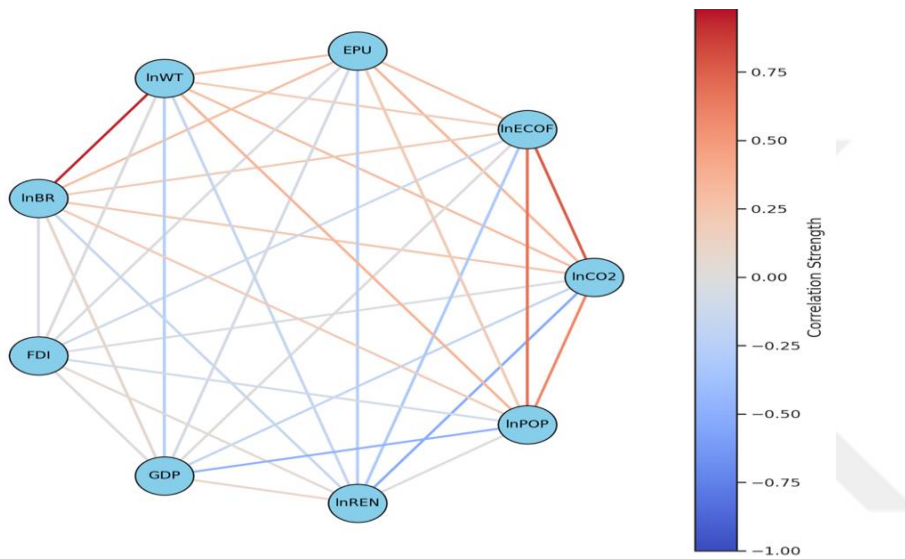


Figure 4.6: Circular Correlation Graph

Table 4.7: Correlation matrix.

Variables	lnCO ₂	lnECOF	EPU	lnWT	lnBR	FDI	GDP	lnREN	lnPOP
lnCO ₂	1.000								
lnECOF	0.750***	1.000							
EPU	0.335***	0.298***	1.000						
lnWT	0.297***	0.199***	0.300***	1.000					
lnBR	0.244***	0.214***	0.293***	0.945***	1.000				
FDI	-0.034	-0.132**	-0.026	-0.013	-0.025	1.000			
GDP	-0.190***	-0.030	-0.057	-0.252***	0.073	-0.011	1.000		
lnREN	-0.516***	-0.300***	-0.257***	-0.149***	-0.149***	0.056	0.117**	1.000	
lnPOP	0.566***	0.659***	0.181***	0.346***	0.190***	-0.088*	-0.501***	0.020	1.000

***, ** explains the level of significance at 1% and 5%, respectively

4.4.3 The symmetric result and discussion

In this study, we examine whether the impacts of EPU, oil prices, and FDI on environmental sustainability, represented by both carbon emissions and the ecological footprint, are symmetric or asymmetric in the short and long term. Consistent with Zhang et al.(2022), the Akaike Information Criterion (AIC) was employed, and the model used a maximum of two lags to ensure robustness. Linear and non-linear ARDL models utilizing PMG, MG, and DFE estimators are applied as described in the methodology section. Table 4.8 presents the symmetric estimation results for carbon emissions and the ecological footprint in Model 1 and Model 2. However, only the PMG estimator results are reported and interpreted, as the Hausman test confirms its suitability with p-values greater than 0.5 for both Model 1 and Model 2 variables.

The Error Correction Term (ECT) coefficient in all models was negative and statistically significant at the 1% level. The values ranged between -0.407 and -0.023. These results indicate the speed at which deviations from the long-run equilibrium are adjusted annually. Specifically, for $\ln\text{CO}_2$, the correction rate is 40.7% in Model 1 and 14% in Model 2. For the $\ln\text{ECOF}$, the correction rate is 34.1% in Model 1 and 2.3% in Model 2. This implies that the speed of adjustment towards equilibrium is more rapid for carbon emissions than for the ecological footprint in the region. Also, the average absolute value of the ECT was approximately 0.25. This indicates that adjustments to deviations from the long-run equilibrium would require roughly two and a half years. Thus, the result suggests the urgent need for immediate and focused policy interventions to safeguard long-term environmental sustainability in SSA countries.

4.4.3.1 Epu and environmental sustainability

Empirical results show that EPU has contrasting effects on SSA's carbon emissions and ecological footprints over the short and long run. In the short run, a unit increase in EPU decreases carbon emissions by 1.2% in Model 1 and 4.2% in Model 2 while increasing $\ln\text{ECOF}$ by 2.3% and 1.1% in Models 1 and 2, respectively. In the long run, however, the same increase in EPU leads to a rise in carbon emissions by 8.4% in Model 1 and 3.5% in Model 2 while reducing ecological footprint consumption by 5.9% and 7.8% across the region.

This result is in line with Anser et al.(2021) and Liu and Zhang (2022), who showed that high EPU reduces emissions in the short run but increases in the long run in the top ten carbon emitter countries, including China. Our results on ecological footprint also concur with the findings of Esmaeili et al.(2023) and Zahra & Badeeb (2022), who found similar trends in energy-intensive and OECD countries, respectively. In contrast, Jiao et al.(2022) and Udeagha & Muchapondwa (2022), argue that EPU positively impacts the ecological footprint in China and South Africa in the short and long run. The findings further show that focusing solely on carbon emissions cannot fully capture environmental sustainability's complexities.

The socio-economic and institutional characteristics of the region may explain the observed results. In the short run, higher uncertainty surrounding economic policies discourages businesses from committing to large or long-term projects that use many fossil fuels. Thus, it reduces industrial activity and carbon emissions in the short run. However, this is offset by increasing reliance on traditional biomass energy (e.g., firewood and charcoal), especially in the rural and informal sectors of the region. The shift also increases the pressure on the ecological footprint as large amounts of land are already fragmented due to deforestation and land degradation. Thus, while carbon emissions may decline, the consumption footprint expands in the short run due to unsustainable resource use.

However, in the long run, delayed investments in renewable energy and sustainable infrastructure during economic uncertainty may lead to a sustained reliance on carbon-intensive energy sources. Thus, it will reverse short-term emission reductions and increase long-term carbon emissions. Simultaneously, reliance on traditional energy sources exhausts natural resources and damages ecosystems, lowering the region's biocapacity. This leads to reduced ecological footprint consumption, not because of sustainable practices but due to diminished resource availability in the area.

Table 4.8: Symmetric PMG estimation result.

Variables	lnCO ₂ (0,0,0,0,0,0,0,0)				lnECOF (0,0,0,0,0,0,0,0)			
	Model 1= lnWT		Model 2 =lnBR		Model 1= lnWT		Model 2 =lnBR	
	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob
Long-run estimates								
EPU	0.084*	0.061	0.035**	0.020	-0.059***	0.000	-0.078***	0.000
lnWT	-0.246***	0.001			-0.026***	0.000		
lnBR			-0.066***	0.001			0.0282***	0.000
FDI	-0.067***	0.000	-0.052***	0.000	-0.001	0.868	-0.005	0.628
GDP	-0.063***	0.001	-0.014*	0.081	0.015**	0.025	0.049**	0.032
lnREN	-0.966***	0.000	-0.028***	0.000	-0.274***	0.000	-0.280***	0.000
lnPOP	4.052**	0.027	1.470***	0.000	1.926***	0.000	1.931***	0.000
Short-run estimates								
ECT (-1)	-0.407***	0.000	-0.140***	0.000	-0.341***	0.002	-0.023***	0.000
D.EPU	-0.012***	0.002	-0.042**	0.022	0.023**	0.013	0.011**	0.031
D. lnWT	-0.030	0.182			-0.003	0.764		
D. lnBR			-0.051	0.302			-0.002	0.358

***, **, * explains the level of significancy at 1%, 5% and 10% respectively.

Table 4.8(continued): Symmetric PMG estimation result.

Variables	lnCO ₂ (0,0,0,0,0,0,0)				lnECOF (0,0,0,0,0,0,0)			
	Model 1= lnWT		Model 2 =lnBR		Model 1= lnWT		Model 2 =lnBR	
	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob
	Short-run estimates							
D.FDI	0.005**	0.046	0.007***	0.000	-0.001	0.567	0.058	0.158
D.GDP	0.003***	0.008	0.00176*	0.051	0.001	0.764	0.016*	0.083
D.lnREN	-0.190	0.493	-0.249	0.205	0.018	0.591	0.127	0.466
D.lnPOP	0.359	0.345	0.543	0.402	0.714***	0.002	5.932***	0.000
Constant	-8.036***	0.000	4.686*	0.072	-5.796***	0.002	-0.058***	0.001
Housman1 (MG vs PMG)	3.57(0.738)		4.29(0.565)		3.68 (0.686)		4.88 (0.423)	

***, **, *explains the level of significance at 1%, 5% and 10% respectively.

4.4.3.2 Oil price and environmental sustainability

We evaluated the effect of oil prices on environmental sustainability indicators by performing separate estimations for Brent crude oil and WTI crude oil. This decision was made due to the strong correlation between the two benchmarks. Joint estimation may result in multicollinearity issues and potentially reduce the accuracy of the results. Thus, by estimating them individually, we improved the robustness and reliability of the findings.

The long-run results reveal that higher oil prices have a negative and statistically significant effect on both carbon emissions and the ecological footprint. A 1% increase in oil prices is associated with a 0.246% decrease in carbon emissions in Model 1 and a 0.066% decrease in Model 2. Similarly, a 1% increase in oil prices is associated with a 0.026% decrease in the ecological footprint in Model 1 but a 0.0282% increase in Model 2. These findings suggest that higher oil prices generally promote environmental sustainability, particularly through reduced carbon emissions, while the effects on the ecological footprint vary across models.

This outcome may be attributed to several factors. First, rising oil prices increase the cost of fossil fuels, which are SSA's primary energy source, making carbon-intensive energy less affordable for businesses and households. This economic pressure encourages a transition from fossil fuels, fostering the adoption of abundant renewable energy alternatives across the region. Such a shift reduces carbon emissions and mitigates environmental degradation associated with oil extraction, transportation, and combustion, thereby contributing to a smaller ecological footprint.

Second, the high cost of oil prices diverts resources to reduce emissions and resource consumption by encouraging the adoption of energy-efficient technologies (e.g., fuel-efficient vehicles and enhanced industrial processes). Moreover, the higher cost associated with petroleum-based fertilizers and machinery also may push the transition to more sustainable agricultural practices like agroecology and organic agriculture. However, these methods generate fewer carbon emissions and have a smaller ecological footprint compared to conventional farming in the long run. Our finding is also consistent with the previous research of Ebaid et al. (2022) and Joof et al. (2023), who reported similar outcomes in GCC and China, respectively. However, our findings diverge from those of Achuo (2022) and Onifade (2023), who posit that higher oil

prices tend to increase carbon emissions in SSA and the ecological footprint of oil-exporting African countries.

However, the short-run effects of oil prices on carbon emissions and ecological footprint were statistically insignificant. Therefore, the change in oil price does not affect environmental performance in the short run of the studied area. Our results are also consistent with the work of Zhang et al. (2022), who showed that oil price has a statistically insignificant effect on carbon emissions in the USA. This is likely to result from the relatively slow adjustment in behavioural and structural terms to fluctuations in price in SSA. The region's energy infrastructure is often characterized by a lack of alternatives to fossil fuels, limiting the ability to respond to short-run price changes. Many African households also face financial constraints that hinder their ability to transition to more sustainable energy consumption patterns in response to price changes. Additionally, the affordability and availability of modern, clean energy alternatives are still significant challenges across the continent.

4.4.3.3 Fdi and environmental sustainability

The empirical result also found the effect of FDI on environmental sustainability interesting. In the long run, FDI inflow reduces emissions in SSA in both Model 1 and Model 2. Specifically, a unit increase in FDI inflow in the region reduces emissions by 6.7%–5.2%. In the short run, the effect becomes positive and significant in both models, with a unit increase in FDI per capita leading to a 0.5%- 0.7% increase in emissions. This finding argues that while FDI harms environmental sustainability in the short run, it improves it in the long run. In other words, the "pollution haven hypothesis" dominates in the short run. However, the "pollution halo hypothesis" becomes more prevalent in the long run.

The short-run result of this finding is consistent with previous studies by Oladipupo and Ajide (2024), who show that FDI inflows increase carbon dioxide emissions in SSA in the short run. There are several possible reasons for this finding: In SSA, FDI inflow is mainly directed towards energy-intensive sectors such as manufacturing, construction, and transportation, which are large carbon emitters, especially in their early stages of operation. Moreover, the environmental regulations and enforcement mechanisms within many SSA countries are relatively weak, allowing foreign

investors to operate while giving little emphasis to sustainability. As a result, carbon emissions may be enhanced by a lack of focused environmental policies.

On the other hand, FDI can have a negative effect on carbon emissions in the region in the long run. This may be due to the transfer of advanced technologies, capital, and expertise, which promote cleaner production methods and the adoption of renewable energy sources. Moreover, FDI may stimulate economic growth that could help to increase environmental regulation in the area in the long run. Many of these policies are backed by foreign investment and help push forth sustainable practices that decrease carbon emissions. These results are also in line with Madzianike (2024), Kim & Seok (2023), Zhao (2022), and Yang et al.(2021), who found that FDI inflow enhances environmental sustainability in Africa, South Korea, and China, respectively. Interestingly, we find no significant effect of FDI inflow on the ecological footprint in both the short and long run. This finding aligns with Doytch (2020), who argues that FDI has an insignificant effect on consumption-based ecological footprints in developing countries. This suggests that while FDI may reduce emissions, it does not address broader environmental challenges, which remain significant in SSA.

4.4.3.4 Control variables and environmental sustainability

The effect of the control variable on environmental sustainability is also exciting and aligns with economic theory. The findings reveal that GDP significantly negatively affects carbon emissions in the long run across both models. However, the short-run effect of GDP has positive and significant. This finding supports the Environmental Kuznets Curve (EKC) hypothesis, which states that environmental degradation rises during the early stages of economic development but falls as economies continue to grow. This result aligns with Goswami et al.(2023) and Teklie and Yağmur (2024), who also support the EKC hypothesis in Africa. However, Selmeý and Elamer (2023) and Osei-Kusi et al.(2024) found the opposite, with a short-run negative and long-run positive relationship.

On the other hand, the finding reveals a positive association between economic growth and the region's ecological footprints in both the long and short run. However, the effect is significant only in the long run. This may be attributed to the SSA's economic dependency on agriculture, which are characterized by the traditional, resource-intensive, and limited adoption of sustainable technologies. This finding contrasts with

the conclusions of Pata and Karlilar Pata (2024), who reported a negative relationship between GDP and ecological footprints in Africa.

As expected, we find that renewable energy consumption is positively associated with environmental sustainability in SSA in the long run. This finding supports the sustainability transition theory, which states that renewable energy improves environmental performance. Our findings are consistent with earlier studies Akpanke et al.(2024), Li et al.(2023) and Thombs (2017) who concluded that renewable energy use reduces per capita carbon emissions and ecological footprint, with more excellent effects in low-income countries. However, in the short run, its impact on carbon emissions and the environmental footprint is negative and insignificant. This result may stem from the fact that the region takes longer to deploy renewable energy infrastructure and phase out traditional energy sources. This short-run effect may also be due to SSA's lack of supportive policies.

In contrast, in SSA population growth, carbon emissions and ecological footprint increase in the long run. In the short run, population growth has a negligible effect on carbon emissions but a significant positive effect on the ecological footprint. The result fits with Malthusian theory, which associates population growth with increases in energy consumption and environmental devastation. These results are in line with previous studies Wang et al.,(2022), Yousaf et al. (2022) and Khan et al.(2021), who have shown that population growth poses environmental challenges. This finding indicates that the region's rapid population growth results in extreme pressure on scarce natural resources, which has immediate impacts on ecosystem degradation and resource depletion. These impacts are especially pronounced in poorly governed areas with limited and poorly managed resource systems, making it even harder to realize a sustainable energy transition.

4.4.4 The asymmetric result and discussion

In this section, we first test for short-run and long-run asymmetries using a Wald test. The Wald test results are given in Table 4.9. The test result reveals that long-run asymmetries are suitable for estimating the effects of EPU, lnWT, and lnBR on carbon emissions and the ecological footprint. Furthermore, although long-run asymmetry is necessary for determining the impact of FDI on carbon emissions, short and long-run asymmetries are needed for examining the effect of FDI on the ecological footprint.

divert government attention toward short-term economic goals at the expense of the environment, discourages international funding for sustainability programs, and delays progress in emissions reduction and conservation initiatives.

However, negative changes in EPU are associated with economic stability and conditions for better environmental governance. This is probably because the region's government finds easier to implement strict environmental policies and regulations during the low EPU period. Furthermore, low EPU attracts foreign investments in the renewable energy and green technology sectors, enabling the region to draw away from old fossil fuels and use cleaner options. Thus, the influx of investment translates to the creation of sustainable infrastructure and technologies that may lead to long-term ecological sustainability. Additionally, a decrease in EPU allows policymakers to put into effect long-term environmental priorities, such as adaptation to climate change and conservation of biodiversity, that can be overlooked during high-uncertainty periods.

Table 4.10: Asymetric PMG estimation result.

Variables	lnCO ₂ (0,0,0,0,0,0,0)				lnECOF (0,0,0,0,0,0,0)			
	Model 1= lnWT		Model 2 =lnBR		Model 1= lnWT		Model 2 =lnBR	
	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob
Long-run estimates								
EPU+	0.065***	0.015	0.112***	0.001	0.072***	0.000	0.066***	0.000
EPU-	-0.059***	0.000	-0.129***	0.000	-0.019	0.366	-0.054**	0.017
lnWT+	-0.011	0.459			-0.048	0.274		
lnWT-	0.235***	0.000			0.116***	0.000		
lnBR+			-0.194***	0.000			-0.135***	0.000
lnBR-			0.269***	0.000			-0.009	0.955
FDI+	0.067	0.164	0.047***	0.001	0.006	0.269	0.006	0.509
FDI-	-0.019***	0.009	-0.020***	0.000	-0.001	0.758	-0.092	0.258
GDP	0.034**	0.016	0.072	0.475	0.085***	0.000	0.066	0.246
lnREN	0.053***	0.000	0.061***	0.000	0.055***	0.000	0.019***	0.000
lnPOP	2.331***	0.000	1.589***	0.000	1.605***	0.000	1.822***	0.000
Short-run estimates								
ECT (-1)	-0.354***	0.003	-0.270***	0.000	-0.421***	0.005	-0.370**	0.016
D.EPU	-0.008	0.182	-0.010	0.417	0.018**	0.049	0.035*	0.0622
D. lnWT	-0.011	0.597			-0.013	0.291		

Table 4.10 (continued): Asymmetric PMG estimation result.

Variables	lnCO ₂ (0,0,0,0,0,0,0)				lnECOF (0,0,0,0,0,0,0)			
	Model 1= lnWT		Model 2 =lnBR		Model 1= lnWT		Model 2 =lnBR	
	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob
	Short-run estimates							
D. lnBR			0.069	0.734			-0.042**	0.092
D.FDI+					0.018**	0.034	0.017*	0.074
D.FDI-					-0.027***	0.006	-0.019**	0.038
D.GDP	0.069	0.119	0.034	0.632	7.05e-05	0.956	0.002	0.574
D.lnREN	5.26e-05	0.514	-3.58e-05	0.156	1.78e-05	0.808	-5.53e-05	0.237
D.lnPOP	0.326	0.392	-0.414	0.401	0.557***	0.004	-0.595**	0.034
Constant	-11.38***	0.004	-5.171***	0.000	-4.136***	0.004	-5.030**	0.0471

***, **, *explains the level of significance at 1%, 5% and 10% respectively.

4.4.4.2 Oil price and environmental sustainability

Further, this study argues that oil price fluctuations have an asymmetric and significant effect on environmental sustainability indicators in the SSA countries in the long run. Model 1 indicates that positive changes to West Texas Intermediate (WT) crude oil prices have an insignificant negative effect on both $\ln\text{CO}_2$ and the $\ln\text{ECOF}$. In Model 2, however, the effect of positive change to Brent crude oil prices on these environmental indicators is statistically significant and negative. The empirical results show that a 1% increase in Brent crude oil prices reduces 19.4% in carbon emissions and 13.5% in ecological footprint. This shows the unique environmental consequences of oil price dynamics in the region. Specifically, it shows that WT crude oil price fluctuations have a negligible impact on SSA ecological sustainability. In contrast, increases in Brent crude oil prices significantly reduce emissions and environmental degradation in the region. This disparity may be attributed to SSA's heavy reliance on Brent-indexed oil markets. Additionally, the results reveal that negative changes in crude oil prices in both Model 1 and Model 2 are associated with statistically significant positive coefficients for carbon emissions at the 1% significance level. The same outcome is observed for the coefficient of adverse shocks to WT crude oil prices on the ecological footprint in Model 1.

The findings may be associated with the substitution and income effect. Positive changes in oil prices likely make fossil fuels more expensive. Thus, it encourages stakeholders to shift toward cleaner energy alternatives such as solar, wind, and hydropower in the long run. The effect might be particularly pronounced in Africa, including SSA, where renewable energy potential is vast but underutilized. As a result, positive changes in oil prices may significantly reduce carbon emissions and the ecological footprint by discouraging resource-intensive practices in the region in the long run. However, negative oil price changes are likely to reduce the cost of fossil fuels, making them more accessible and encouraging their consumption. This could lead to a greater reliance on carbon-intensive energy sources, possibly driving emissions and expanding the ecological footprint through intensified environmental degradation. The income effect is also may contribute to the observed relationship between oil price changes and environmental outcomes in the region. Rising oil prices strain household and government budgets, potentially limiting energy consumption and indirectly curbing carbon emissions and ecological exploitation. On the other

hand, negative changes in oil prices could lower energy costs, encouraging greater fossil fuel consumption and possibly driving up emissions. Additionally, increased energy affordability from cheaper oil might accelerate unsustainable practices, potentially enlarging the ecological footprint.

The findings of this study diverge from those of Hassan & Mhlanga (2023) and Mahmood et al. (2020a), who reported that positive changes in crude oil prices contribute to an increase in the ecological footprint of oil-producing African countries and carbon emissions in Saudi Arabia. In contrast, negative changes result in a reduction of these impacts. However, these findings align with Okwanya et al. (2023) and Joof et al. (2023), who demonstrated that rising oil prices mitigate China's ecological footprint, whereas declining oil prices exacerbate African carbon emissions. Furthermore, these findings are consistent with the studies by Boufateh (2021) and Malik et al., (2020), who observed that changes in oil prices do not have a uniform effect on environmental quality.

4.4.4.3 Fdi and environmental sustainability

Following the Wald test result, we find that FDI's effect on carbon emissions is asymmetric only in the long run. However, its impact on ecological footprint is asymmetric both in the short and long run. The long-run results reveal that a positive change to the FDI coefficient positively affects CO₂ emissions, but this effect is insignificant in Model 1. However, in Model 2, a positive shock in FDI leads to a significant 4.7% increase in CO₂ emissions. This implies that increased FDI contributes to higher carbon emissions in the region. On the other hand, a negative change to FDI significantly reduces CO₂ emissions in both models, with a 1.9% reduction in Model 1 and a 2% reduction in Model 2. These findings reveal that the increase in emissions caused by positive FDI shocks marginally outweighs the reduction in emissions from adverse FDI shocks.

Based on these findings, it can be inferred that the "Pollution Haven" (PH) hypothesis holds for SSA countries in the long run. These results also align with Abdul-Mumuni et al.(2022), who also demonstrated that a positive change in FDI leads to higher carbon emissions in the host country in the long run. From this result, we can conclude that the asymmetric methodology is superior to the symmetric approach. Without

employing an asymmetric analysis, we might have incorrectly concluded that the long-run impact of FDI on CO₂ emissions in these countries is negative.

Similarly, the long-run results reveal no significant effect from positive or negative FDI shocks on lnECOF in both Model 1 and Model 2. However, in the short run, a significant asymmetric effect is observed. A positive FDI shock significantly increases ecological footprint consumption, while a negative shock reduces it. Specifically, a 1% increase in the FDI coefficient leads to a 1.8% and 1.7% increase in lnECOF in Models 1 and 2, respectively. Similarly, a 1% decrease in the FDI coefficient results in a 2.7% and 1.9% decrease in lnECOF in Models 1 and 2, respectively. These findings are consistent with Van Tran et al. (2024) in Indonesia, who conclude the presence of short-run and long-run asymmetry but no significant long-run effects.

This outcome probably stems from the unique characteristics of FDI inflows to the region. Several interconnected factors may cause positive FDI shocks in SSA to increase the ecological footprint in the short run. First, FDI inflow in SSA is often directed to extractive industries such as agriculture, mining, and forestry. These sectors are resource-intensive and require large-scale extraction and use of natural resources. On the other hand, this increased exploitation of natural resources may directly deplete the Earth's biocapacity. Therefore, the short-run ecological footprint increases in the region.

Second, the inflows of FDI in the region frequently help finance infrastructure development, including roads, dams, and industrial facilities. However, these investments often rely on outdated, resource-intensive, inefficient, and unsustainable technologies. They, therefore, result in extensive land clearing, excessive use of natural resources, and considerable waste generation at the construction and operation stages. This depletes resources faster than ecosystems can recover, thus increasing the region's ecological footprint. Also, the region's regulatory frameworks and environmental policies are weak. Due to this weakness in institutions, foreign investors usually prioritize short-term economic interests to sustainability. Consequently, to achieve maximum immediate profits, they perform rapid resource exploitation. However, such practices may lead to natural resource overexploitation and, therefore, higher regional ecological consumption.

However, in the short run, an adverse change in FDI inflows in SSA mitigates ecological consumption. This is probably due to reduced foreign capital, which slowed

down industrial and extractive activities, thereby controlling demand for energy-intensive activities and the use of natural resources. Moreover, FDI is relied upon by many resource-dependent industries in SSA, and when these inflows decline, the scale of resource use drops significantly. Moreover, negative changes in FDI lead to temporary economic stagnation, stopping various infrastructure projects and reducing industrial production and consumption of ecological resources. Moreover, this result shows the need for symmetric modeling to capture better FDI's impact, which is not evident in linear analysis. Also, the asymmetric effects of the control variables and the ECT are consistent with their symmetric counterparts, irrespective of the coefficient values.

4.4.5 Robustness checks

The stationarity of residuals is important to verify the reliability and consistency of PMG/ARDL model estimations (Pesaran, 2007b). Model stability requires that the residuals are free from unit roots. To this end, panel unit root tests were performed using the "Levin-Lin-Chu, Im-Pesaran-Shin, and Breitung" methods. These test results are reported in Tables 4.11 and 4.12 for the symmetric and asymmetric estimations.

Table 4.11: Residual unit root test for symmetric PMG/ARDL model.

Test	lnCO ₂				lnECOF			
	Model 1= lnWT		Model 2 =lnBR		Model 1= lnWT		Model 2 =lnBR	
	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value
Levin-Lin-Chu	- 11.473	0.000	- 13.01 4	0.000	- 15.01 6	0.000	- 11.11 8	0.000
Im-Pesaran-Shin	- 16.456	0.000	- 15.18 9	0.000	- 21.25 6	0.000	- 15.23 9	0.000
Breitung	- 13.629	0.000	- 12.55 7	0.000	- 18.10 1	0.000	- 12.34 2	0.000

***explains the level of significance at 1%

Table 4.12: Residual unit root test for the asymmetric PMG/ARDL model.

Test	lnCO ₂				lnECOF			
	Model 1= lnWT		Model 2 =lnBR		Model 1= lnWT		Model 2 =lnBR	
	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value
Levin-Lin-Chu	- 9.176	0.000	- 11.07 6	0.000	- 10.34 5	0.000	- 14.5 20	0.000
Im-Pesaran-Shin	- 23.257	0.000	- 20.13 2	0.000	- 21.52 4	0.000	- 18.1 48	0.000
Breitung	- 14.572	0.000	- 18.16 84	0.000	- 11.83 2	0.000	- 16.2 36	0.000

***, explains the level of significance at 1%

The results from the residual unit root tests for both the symmetric and asymmetric PMG/ARDL models validate that all residuals are stationary at the level. This stationarity is evidenced across all tests, with significance at the 1% level. These findings thus validate the stability of the estimated models and prove that the PMG/ARDL results are robust and appropriate for inference. This robustness ensures the conclusions' reliability, aligning with prior research findings by Achuo (2022) and Fonchamnyo et al.(2021).

4.5 Conclusion and Policy Implication

Environmental degradation has become a key challenge for decades, particularly in regions such as SSA, where insufficient regulations and policies will catastrophically affect the economies, ecosystems, and human survival. Using the top 10 carbon-emitting SSA countries, this study analysed the symmetric and asymmetric impacts of three important factors (Economic Policy Uncertainty (EPU), oil prices, and Foreign Direct Investment (FDI)) on environmental sustainability indicators (carbon emissions and ecological footprint) in the short and long run. Moreover, the way GDP, renewable energy, and population affect these indicators was also investigated.

The methodological approach used a comprehensive framework that included the second-generation panel cointegration technique to deal with cross-sectional dependence and slope heterogeneity and CADF and CIPS tests for stationarity. Long-term relationships were determined using the Westerlund (2007) technique, and symmetric and asymmetric effects were estimated using the ARDL and NARDL/PMG models. Residual unit root tests ensured the robustness of the results, and the Wald test assessed the existence of asymmetries in the model. The results show that EPU, oil prices, and FDI significantly impact environmental sustainability but have different short- and long-term effects.

Symmetrically, EPU was found to increase the ecological footprint in the short run but to decrease it in the long run. In the long run, oil prices symmetrically decrease carbon emissions and the ecological footprint while having negligible short-run effects. In the long run, FDI reduces carbon emissions, but in the short run, it increases them, with no significant symmetric effect on ecological footprint. Positive changes in EPU and FDI increase emissions and ecological footprint asymmetrically, while unfavorable

changes reduce both. On the other hand, positive oil price shocks decrease emissions and ecological pressures, while negative shocks increase them.

Based on these findings, several policy recommendations are made. In the short term, in response to increasing EPU, governments in SSA should introduce temporary safeguards, including resource use caps, more stringent environmental impact assessments (EIAs), and incentives for businesses to adopt energy-efficient technologies. Establishing real-time environmental monitoring frameworks for compliance should also be done. As measures in the long term, investments in renewable energy infrastructure, as well as the implementation of carbon pricing mechanisms such as carbon taxes or cap and trade systems, will decrease reliance on fossil fuels and lessen carbon emissions.

The asymmetric effects of EPU require policymakers to adopt resilience-oriented strategies. When EPU is high, governments should impose stricter emission caps and force the use of low-carbon technologies. In low EPU times, priorities should be reforestation, land rehabilitation, and biodiversity conservation. Stability funds should also be established to buffer ecological risks and maintain sustainable investment flows during economic volatility.

The results on oil price dynamics imply that SSA governments should take advantage of high oil prices to shift to renewable energy. Critical are investments in clean energy infrastructure, subsidies for renewable energy adoption, and developing off-grid solutions for rural areas. This implies that countries with lead exports, such as Nigeria, Sudan, and Angola, should place the surplus oil revenue in green funds that favor investment projects like investing in energy-efficient transportation, electrification programs, and clean cooking technologies. Governments must stabilize emission controls, keep energy efficiency regulations in place, and put constant carbon taxes in place to offset the harmful environmental effects of falling oil prices.

SSA governments are also taking steps to reduce oil price volatility, diversify energy sources, and develop regional renewable energy grids. Further enhancing sustainability will require oil companies to undertake Corporate Social Responsibility (CSR) initiatives focusing on reforestation, land rehabilitation, and community-based ecological conservation.

To maximize the environmental benefits of FDI, SSA governments must focus on short-term carbon emission management by imposing clean technologies and energy-efficient production systems on foreign investors, especially in carbon-intensive sectors such as manufacturing and mining. We argue that carbon pricing mechanisms such as taxes or cap and trade should reward emission reduction and that revenues should be driven into renewable energy infrastructure and environmental restoration projects. Over the long term, governments should aim at attracting green FDI via incentives such as tax breaks, subsidies, and preferential financing for renewable energy, clean manufacturing, and sustainable infrastructure. In addition, sector-specific regulations are needed to control FDI fluctuations by imposing higher standards during surges and encouraging restoration programs during declines. In this regard, foreign investors' CSR programs include ecological restoration, biodiversity conservation, water resource management, and sustainable land use.

Despite its contributions to the literature, this study also has limitations. First, it focuses only on the top 10 carbon-emitting SSA countries. Second, the study used consumption-based ecological footprint indicators, excluding production-based measures. Thus, future studies in the area may expand the scope to include more SSA countries to capture regional diversity and integrate production-based indicators for a more holistic view of environmental sustainability. Addressing these limitations will enhance the depth and applicability of future studies.



REFERENCES

- Abbas, Z., Afshan, G., & Mustifa, G.** (2022). The effect of financial development on economic growth and income distribution: an empirical evidence from lower-middle and upper-middle-income countries. *Development Studies Research*, 9(1), 117–128. <https://doi.org/10.1080/21665095.2022.2065325>
- Abbasi, K. R., & Adedoyin, F. F.** (2021). Do energy use and economic policy uncertainty affect CO₂ emissions in China? Empirical evidence from the dynamic ARDL simulation approach. *Environmental Science and Pollution Research*, 28, 23323–23335. <https://doi.org/10.1007/s11356-020-12217-6>
- Abbass, K., Song, H., Mushtaq, Z., & Khan, F.** (2022). Does technology innovation matter for environmental pollution? Testing the pollution halo/haven hypothesis for Asian countries. *Environmental Science and Pollution Research*, 29(59), 89753–89771. <https://doi.org/10.1007/s11356-022-21929-w>
- Abdul-Mumuni, A., Amoh, J. K., & Mensah, B. D.** (2022). Does foreign direct investment asymmetrically influence carbon emissions in sub-Saharan Africa? Evidence from nonlinear panel ARDL approach. *Environmental Science and Pollution Research*, 30(5), 11861–11872. <https://doi.org/10.1007/s11356-022-22909-w>
- Abid, M.** (2016). Impact of economic, financial, and institutional factors on CO₂ emissions: Evidence from Sub-Saharan Africa economies. *Utilities Policy*, 41, 85–94. <https://doi.org/10.1016/j.jup.2016.06.009>
- Abid, M.** (2017). Does economic, financial and institutional developments matter for environmental quality? A comparative analysis of EU and MEA countries. *Journal of Environmental Management*, 188(2), 183–194. <https://doi.org/10.1016/j.jenvman.2016.12.007>
- Abid, N., Ceci, F., Ahmad, F., & Aftab, J.** (2022). Financial development and green innovation, the ultimate solutions to an environmentally sustainable society: Evidence from leading economies. *Journal of Cleaner Production*, 369(July), 133223. <https://doi.org/10.1016/j.jclepro.2022.133223>
- Abumunshar, M., Aga, M., & Samour, A.** (2020). Oil Price, Energy Consumption, and CO₂ Emissions in Turkey. New Evidence from a Bootstrap ARDL Test. *Energies*, 13(21), 5588. <https://doi.org/10.3390/en13215588>
- Acemoglu, D., Akcigit, U., Hanley, D., & Kerr, W.** (2016). Transition to Clean Technology. *Journal of Political Economy*. [https://doi.org/0022-3808/2016/12401-0003\\$10.00](https://doi.org/0022-3808/2016/12401-0003$10.00)
- Acemoglu, Daron, & Robinson, J.** (2010). The Role of Institutions in Growth and Development. In *Review of Economics and Institutions* (Vol. 1, Issue 2). <https://doi.org/10.5202/rei.v1i2.1>

- Acheampong, A. O.** (2019). Modelling for insight: Does financial development improve environmental quality? *Energy Economics*, 83, 156–179. <https://doi.org/10.1016/j.eneco.2019.06.025>
- Acheampong, A. O.** (2022). The impact of de facto globalization on carbon emissions: Evidence from Ghana. *International Economics*, 170(March), 156–173. <https://doi.org/10.1016/j.inteco.2022.03.002>
- Acheampong, A. O., Adams, S., & Boateng, E.** (2019). Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? *Science of the Total Environment*, 677, 436–446. <https://doi.org/10.1016/j.scitotenv.2019.04.353>
- Acheampong, A. O., Boateng, E., Amponsah, M., & Dzator, J.** (2021). Revisiting the economic growth–energy consumption nexus: Does globalization matter? *Energy Economics*, 102(December 2020), 105472. <https://doi.org/10.1016/j.eneco.2021.105472>
- Achuo, E. D.** (2022). The nexus between crude oil price shocks and environmental quality: empirical evidence from sub-Saharan Africa. *SN Business & Economics*, 2(7), 79. <https://doi.org/10.1007/s43546-022-00264-9>
- Adebayo, T. S., Pata, U. K., & Akadiri, S. Saint.** (2024). A comparison of CO₂ emissions, load capacity factor, and ecological footprint for Thailand’s environmental sustainability. *Environment, Development and Sustainability*, 26(1), 2203–2223. <https://doi.org/10.1007/s10668-022-02810-9>
- Adeel-Farooq, R. M., Riaz, M. F., & Ali, T.** (2021). Improving the environment begins at home: Revisiting the links between FDI and environment. *Energy*, 215, 119150. <https://doi.org/10.1016/j.energy.2020.119150>
- African Development Bank.** (2014). *Tracking Africa’s Progress in Figures*. http://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Tracking_Africa’s_Progress_in_Figures.pdf
- Agbanike, T. F., Nwani, C., Uwazie, U. I., Anochiwa, L. I., Onoja, T.-G. C., & Ogbonnaya, I. O.** (2019). Oil price, energy consumption and carbon dioxide (CO₂) emissions: insight into sustainability challenges in Venezuela. *Latin American Economic Review*, 28(1), 8. <https://doi.org/10.1186/s40503-019-0070-8>
- Ahir, H., Bloom, N., & Furceri, D.** (2024). *World Uncertainty Index: Africa [WUIAFRICA]*, retrieved from FRED, Federal Reserve Bank of St. Louis.
- Ahmad, M., Ahmed, Z., Yang, X., Hussain, N., & Sinha, A.** (2022). Financial development and environmental degradation: Do human capital and institutional quality make a difference? *Gondwana Research*, 105, 299–310. <https://doi.org/10.1016/j.gr.2021.09.012>
- Ahmad, M., Jiang, P., Majeed, A., Umar, M., Khan, Z., & Muhammad, S.** (2020). The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: An advanced panel data estimation. *Resources Policy*, 69(September), 101817. <https://doi.org/10.1016/j.resourpol.2020.101817>

- Ahmed, F., Kousar, S., Pervaiz, A., Trinidad-Segovia, J. E., Casado-Belmonte, M. del P., & Ahmed, W.** (2021). Role of green innovation, trade and energy to promote green economic growth: a case of South Asian Nations. *Environmental Science and Pollution Research*, 29(5), 6871–6885. <https://doi.org/10.1007/s11356-021-15881-4>
- Akadiri, S. Saint, & Adebayo, T. S.** (2022). Retracted article: Asymmetric nexus among financial globalization, non-renewable energy, renewable energy use, economic growth, and carbon emissions: impact on environmental sustainability targets in India. *Environmental Science and Pollution Research*, 29(11), 16311–16323. <https://doi.org/10.1007/s11356-021-16849-0>
- Akinsola, M., & Odhiambo, N.** (2020). EuroEconomica The Dynamics of Oil Price and Economic Growth in Six Low-Income Sub-Saharan African Countries EuroEconomica. *EuroEconomica*, 3(3), 74–88.
- Akpanke, T. A., Deka, A., Ozdeser, H., & Seraj, M.** (2024). Ecological footprint in the OECD countries: do energy efficiency and renewable energy matter? *Environmental Science and Pollution Research*, 31(10), 15289–15301. <https://doi.org/10.1007/s11356-024-32151-1>
- Al-Maamary, H. M. S., Kazem, H. A., & Chaichan, M. T.** (2017). The impact of oil price fluctuations on common renewable energies in GCC countries. *Renewable and Sustainable Energy Reviews*, 75, 989–1007. <https://doi.org/10.1016/j.rser.2016.11.079>
- Al-Nimer, M., Kayed, S., Ullah, R., Khan, N. U., & Khattak, M. S.** (2022). Mapping the Research between Foreign Direct Investment and Environmental Concerns; Where Are We and Where to Go? *Sustainability*, 14(24), 16930. <https://doi.org/10.3390/su142416930>
- Aladejare, S. A.** (2022). Natural resource rents, globalisation and environmental degradation: New insight from 5 richest African economies. *Resources Policy*, 78(July), 102909. <https://doi.org/10.1016/j.resourpol.2022.102909>
- Alaganthiran, J., Anaba, M. I., R. Alaganthiran, J., Anaba, M. I., Alaganthiran, J., & Anaba, M. I.** (2022). The effects of economic growth on carbon dioxide emissions in selected Sub-Saharan African (SSA) countries. *Heliyon*, 8(11), e11193. <https://doi.org/10.1016/j.heliyon.2022.e11193>
- Aljefri, Y. M., Hipel, K. W., & Fang, L.** (2013). The Way Forward after the Durban Climate Change Conference: A Strategic Analysis. *2013 IEEE International Conference on Systems, Man, and Cybernetics*, 1783–1788. <https://doi.org/10.1109/SMC.2013.308>
- Altıntaş, H., & Kassouri, Y.** (2020). Is the environmental Kuznets Curve in Europe related to the per-capita ecological footprint or CO₂ emissions? *Ecological Indicators*, 113, 106187. <https://doi.org/10.1016/j.ecolind.2020.106187>
- Aluko, O. A., & Obalade, A. A.** (2020). Financial development and environmental quality in sub-Saharan Africa: Is there a technology effect? *Science of the Total Environment*, 747, 141515. <https://doi.org/10.1016/j.scitotenv.2020.141515>

- Amer, E. A. A., Meyad, E. M. A., Meyad, A. M., & Mohsin, A. K. M.** (2024). The impact of natural resources on environmental degradation: a review of ecological footprint and CO₂ emissions as indicators. *Frontiers in Environmental Science*, 12. <https://doi.org/10.3389/fenvs.2024.1368125>
- Amuakwa-Mensah, F., & Adom, P. K.** (2017). Quality of institution and the FEG (forest, energy intensity, and globalization) -environment relationships in sub-Saharan Africa. *Environmental Science and Pollution Research*, 24(21), 17455–17473. <https://doi.org/10.1007/s11356-017-9300-2>
- Ansari, M. A.** (2022). Re-visiting the Environmental Kuznets curve for ASEAN: A comparison between ecological footprint and carbon dioxide emissions. *Renewable and Sustainable Energy Reviews*, 168, 112867. <https://doi.org/10.1016/j.rser.2022.112867>
- Ansari, M. A., Ahmad, M. R., Siddique, S., & Mansoor, K.** (2020). An environment Kuznets curve for ecological footprint: Evidence from GCC countries. *Carbon Management*, 11(4), 355–368. <https://doi.org/10.1080/17583004.2020.1790242>
- Anser, M. K., Apergis, N., & Syed, Q. R.** (2021). Impact of economic policy uncertainty on CO₂ emissions: evidence from top ten carbon emitter countries. *Environmental Science and Pollution Research*, 28(23), 29369–29378. <https://doi.org/10.1007/s11356-021-12782-4>
- Anser, M. K., Syed, Q. R., Lean, H. H., Alola, A. A., & Ahmad, M.** (2021). Do economic policy uncertainty and geopolitical risk lead to environmental degradation? Evidence from emerging economies. *Sustainability (Switzerland)*, 13(11). <https://doi.org/10.3390/su13115866>
- Antweiler, W., Copeland, B. R., & Taylor, M. S.** (2001). Is free trade good for the environment? *American Economic Review*, 91(4), 877–908. <https://doi.org/10.1257/aer.91.4.877>
- Antwi, F., Kong, Y., & Donkor, M.** (2024). Greening African economies: Investigating the role of financial development, green investments, and institutional quality. *Sustainable Development*, 32(5), 5659–5676. <https://doi.org/10.1002/sd.2958>
- Arellano, M., & Bond, S.** (1991). Some Test of Specification for Data Panel: Monte Carlo Evidence and an Application of Employment Equations. *Source: The Review of Economic Studies*, 58(2), 277–297. doi:10.2307/2297968
- Arellano, M., & Honoré, B.** (2001). Panel Data Models: Some Recent Developments. In *Handbook of Econometrics* (Vol. 5, pp. 3229–3296). [https://doi.org/10.1016/S1573-4412\(01\)05006-1](https://doi.org/10.1016/S1573-4412(01)05006-1)
- Asongu, S., & Odhiambo, N. M.** (2021). Trade and FDI thresholds of CO₂ emissions for a Green economy in sub-Saharan Africa. *International Journal of Energy Sector Management*, 15(1), 227–245. <https://doi.org/10.1108/IJESM-06-2020-0006>
- Asoni, A.** (2008). Protection of property rights and growth as political equilibria. *Journal of Economic Surveys*, 22(5), 953–987. <https://doi.org/10.1111/j.1467-6419.2008.00554.x>

- Assamoi, G. R., & Wang, S.** (2022). Asymmetric effects of economic policy uncertainty and environmental policy stringency on environmental quality: evidence from China and the United States. *Environmental Science and Pollution Research*, 30(11), 29996–30016. <https://doi.org/10.1007/s11356-022-24082-6>
- Audi, M., & Ali, A.** (2018). Determinants of Environmental Degradation Under the Perspective of Globalization: a Panel Analysis of Selected Mena Nations. *Journal of Academy of Business and Economics*, 18(1), 149–166. <https://doi.org/10.18374/jabe-18-1.13>
- Awodumi, O. B., & Adewuyi, A. O.** (2020). The role of non-renewable energy consumption in economic growth and carbon emission: Evidence from oil producing economies in Africa. *Energy Strategy Reviews*, 27, 100434. <https://doi.org/10.1016/j.esr.2019.100434>
- Aye, G. C., & Edoja, P. E.** (2017). Effect of economic growth on CO₂ emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Economics and Finance*, 5(1). <https://doi.org/10.1080/23322039.2017.1379239>
- Ayompe, L. M., Davis, S. J., & Egoh, B. N.** (2020). Trends and drivers of African fossil fuel CO₂ emissions 1990-2017. *Environmental Research Letters*, 15(12). <https://doi.org/10.1088/1748-9326/abc64f>
- Azam, M., & Emirullah, C.** (2014). The role of governance in economic development evidence from some selected countries in Asia and the Pacific. *International Journal of Social Economics*, 41(12), 1265–1278. <https://doi.org/10.1108/IJSE-11-2013-0262>
- Baffes, J., Kose, M. A., Ohnsorge, F., & Stocker, M.** (2015). The Great Plunge in Oil Prices: Causes, Consequences, and Policy Responses. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.2624398>
- Baker, S. R., Bloom, N., Davis, S. J., Dashkeyev, V., Deriy, O., Dinh, E., Ezure, Y., Gong, R., Jindal, S., Kim, R., Klosin, S., Koh, J., Lajewski, P., Sachs, R., Shibata, I., Stephenson, C., & Takeda, N.** (2016). Measuring economic policy uncertainty. *The Quarterly Journal of Economics*, 131(4), 1593–1636. <https://doi.org/10.1093/qje/qjw024>. Advance
- Bangake, C., & Eggoh, J. C.** (2012). Pooled Mean Group estimation on international capital mobility in African countries. *Research in Economics*, 66(1), 7–17. <https://doi.org/10.1016/j.rie.2011.06.001>
- Barassi, M. R., & Spagnolo, N.** (2012). Linear and non-linear causality between CO₂ emissions and economic growth. *Energy Journal*, 33(3), 23–38. <https://doi.org/10.5547/01956574.33.3.2>
- Batrancea, L., Rathnaswamy, M. M., & Batrancea, I.** (2021). A Panel Data Analysis of Economic Growth Determinants in 34 African Countries. *Journal of Risk and Financial Management*, 14(6), 260. <https://doi.org/10.3390/jrfm14060260>

- Bekun, F. V., Gyamfi, B. A., Etokakpan, M. U., & Çakir, B.** (2023). Revisiting the pollution haven hypothesis within the context of the environmental Kuznets curve. *International Journal of Energy Sector Management*. <https://doi.org/10.1108/IJESM-12-2020-0013>
- Bell, J. E., Brown, C. L., Conlon, K., Herring, S., Kunkel, K. E., Lawrimore, J., Luber, G., Schreck, C., Smith, A., & Uejio, C.** (2018). Changes in extreme events and the potential impacts on human health. *Journal of the Air & Waste Management Association*, 68(4), 265–287. <https://doi.org/10.1080/10962247.2017.1401017>
- Bénassy-Quéré, A., Coupet, M., & Mayer, T.** (2007). Institutional Determinants of Foreign Direct Investment. *The World Economy*, 30(5), 764–782. <https://doi.org/10.1111/j.1467-9701.2007.01022.x>
- Benlemlih, M., Assaf, C., & El Ouadghiri, I.** (2022). Do political and social factors affect carbon emissions? Evidence from international data. *Applied Economics*, 54(52), 6022–6035. <https://doi.org/10.1080/00036846.2022.2056128>
- Benlemlih, M., & Yavaş, Ç. V.** (2024). Economic Policy Uncertainty and Climate Change: Evidence from CO₂ Emission. *Journal of Business Ethics*, 191(3), 415–441. <https://doi.org/10.1007/s10551-023-05389-x>
- Bergougui, B., Mehibel, S., & Boudjana, R. H.** (2024). Asymmetric nexus between green technologies, economic policy uncertainty, and environmental sustainability: Evidence from Algeria. *Journal of Environmental Management*, 360, 121172. <https://doi.org/10.1016/j.jenvman.2024.121172>
- Bhuiyan, M. A., Zhang, Q., Khare, V., Mikhaylov, A., Pinter, G., & Huang, X.** (2022). Renewable Energy Consumption and Economic Growth Nexus—A Systematic Literature Review. *Frontiers in Environmental Science*, 10(April), 1–21. <https://doi.org/10.3389/fenvs.2022.878394>
- Bilgili, F., Koçak, E., & Bulut, Ü.** (2016). The dynamic impact of renewable energy consumption on CO₂ emissions: A revisited Environmental Kuznets Curve approach. *Renewable and Sustainable Energy Reviews*, 54, 838–845. <https://doi.org/10.1016/j.rser.2015.10.080>
- Bishoge, O. K., Kombe, G. G., & Mvile, B. N.** (2020). Renewable energy for sustainable development in sub-Saharan African countries: Challenges and way forward. *Journal of Renewable and Sustainable Energy*, 12(5). <https://doi.org/10.1063/5.0009297>
- Blundell, R., & Bond, S.** (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, 87(1), 115–143. [https://doi.org/10.1016/S0304-4076\(98\)00009-8](https://doi.org/10.1016/S0304-4076(98)00009-8)
- Boamah, K. B., Du, J., Bediako, I. A., Boamah, A. J., Abdul-Rasheed, A. A., & Owusu, S. M.** (2017). Carbon dioxide emission and economic growth of China—the role of international trade. *Environmental Science and Pollution Research*, 24(14), 13049–13067. <https://doi.org/10.1007/s11356-017-8955-z>
- Boufateh, T.** (2021). The environmental issue facing asymmetric oil price shocks and renewable energy challenges: evidence from Tunisia. *Environmental Science and Pollution Research*, 28(35), 48207–48221. <https://doi.org/10.1007/s11356-021-14114-y>

- Bu, M., Lin, C. Te, & Zhang, B.** (2016). Globalization and Climate Change: New Empirical Panel Data Evidence. *Journal of Economic Surveys*, 30(3t), 577–595. <https://doi.org/10.1111/joes.12162>
- Bui, D. T.** (2020). Transmission channels between financial development and CO₂ emissions: A global perspective. *Heliyon*, 6(11), e05509. <https://doi.org/10.1016/j.heliyon.2020.e05509>
- Carleton, T. A., & Hsiang, S. M.** (2016). Social and economic impacts of climate. *Science*, 353(6304). <https://doi.org/10.1126/science.aad9837>
- CDP.** (2020). *CDP Africa report: benchmarking progress towards climate safe cities, states, and regions.* (Issue March). https://cdn.cdp.net/cdp-production/cms/reports/documents/000/005/023/original/CDP_Africa_Report_2020.pdf?1583855467
- Chang, C.** (2011). *The Influence of Corporate Environmental Ethics on Competitive Advantage: The Mediation Role of Green Innovation.* 361–370. <https://doi.org/10.1007/s10551-011-0914-x>
- Chang, J. J., Wang, W. N., & Shieh, J. Y.** (2018). Environmental rebounds/backfires: Macroeconomic implications for the promotion of environmentally-friendly products. *Journal of Environmental Economics and Management*, 88, 35–68. <https://doi.org/10.1016/j.jeem.2017.09.004>
- Chaudhry, I. S., Azali, M., Faheem, M., & Ali, S.** (2020). Asymmetric Dynamics of Oil Price and Environmental Degradation: Evidence from Pakistan. *Review of Economics and Development Studies*, 6(1), 1–12. <https://doi.org/10.47067/reads.v6i1.179>
- Chen, R., Ramzan, M., Hafeez, M., & Ullah, S.** (2023). Green innovation-green growth nexus in BRICS: Does financial globalization matter? *Journal of Innovation and Knowledge*, 8(1), 100286. <https://doi.org/10.1016/j.jik.2022.100286>
- Chen, Z., Paudel, K. P., & Zheng, R.** (2022). Pollution halo or pollution haven: assessing the role of foreign direct investment on energy conservation and emission reduction. *Journal of Environmental Planning and Management*, 65(2), 311–336. <https://doi.org/10.1080/09640568.2021.1882965>
- Chu, L. K., Doğan, B., Abakah, E. J. A., Ghosh, S., & Albeni, M.** (2023). Impact of economic policy uncertainty, geopolitical risk, and economic complexity on carbon emissions and ecological footprint: an investigation of the E7 countries. *Environmental Science and Pollution Research*, 30(12), 34406–34427. <https://doi.org/10.1007/s11356-022-24682-2>
- Chu, L. K., & Le, N. T. M.** (2022). Environmental quality and the role of economic policy uncertainty, economic complexity, renewable energy, and energy intensity: the case of G7 countries. *Environmental Science and Pollution Research*, 29(2), 2866–2882. <https://doi.org/10.1007/s11356-021-15666-9>
- Chukwu, V. E.** (2020). Potentials, drivers and barriers to green economy transition: Implications for Africa. *Advanced Journal of Plant Biology*, 1(1), 7–17. <https://doi.org/10.31248/AJPB2020.006>

- Chukwuemeka, N. S., Ugonna, A. P., Ugochukwu, O. B., Immaculata, E. N., Chiziterem, E. K., & Chukwubuikem, O. P.** (2023). The Challenges and Opportunities of Energy Transition across Africa. *International Journal of Environment and Climate Change*, 13(10), 4312–4339. <https://doi.org/10.9734/ijecc/2023/v13i103109>
- Clarke, B., Otto, F., Stuart-Smith, R., & Harrington, L.** (2022). Extreme weather impacts of climate change: an attribution perspective. *Environmental Research: Climate*, 1(1), 012001. <https://doi.org/10.1088/2752-5295/ac6e7d>
- Dam, M. M., Durmaz, A., Bekun, F. V., & Tiwari, A. K.** (2024). The role of green growth and institutional quality on environmental sustainability: A comparison of CO₂ emissions, ecological footprint and inverted load capacity factor for OECD countries. *Journal of Environmental Management*, 365, 121551. <https://doi.org/10.1016/j.jenvman.2024.121551>
- Danish, & Ulucak, R.** (2020). How do environmental technologies affect green growth? Evidence from BRICS economies. *Science of the Total Environment*, 712, 136504. <https://doi.org/10.1016/j.scitotenv.2020.136504>
- Danish, & Ulucak, R.** (2021). Renewable energy, technological innovation and the environment: A novel dynamic auto-regressive distributive lag simulation. *Renewable and Sustainable Energy Reviews*, 150(July), 111433. <https://doi.org/10.1016/j.rser.2021.111433>
- Danish, Ulucak, R., & Khan, S.** (2020). Relationship between energy intensity and CO₂ emissions: Does economic policy matter? *Sustainable Development*, 28(5), 1457–1464. <https://doi.org/10.1002/sd.2098>
- Dechezleprêtre, A., Rivers, N., & Stadler, B.** (2020). *The Economic Cost Of Air Pollution: Evidence From Europe Economics* (No. 1584; Issue ECO/WKP(2019)54).
- Demena, B. A., & Afesorgbor, S. K.** (2020). The effect of FDI on environmental emissions: Evidence from a meta-analysis. *Energy Policy*, 138, 111192. <https://doi.org/10.1016/j.enpol.2019.111192>
- Deyshappriya, N. P. R., Rukshan, I. A. D. D. W., & Padmakanthi, N. P. D.** (2023). Impact of Oil Price on Economic Growth of OECD Countries: A Dynamic Panel Data Analysis. *Sustainability*, 15(6), 4888. <https://doi.org/10.3390/su15064888>
- Dong, K., Hochman, G., Zhang, Y., Sun, R., Li, H., & Liao, H.** (2018). CO₂ emissions, economic and population growth, and renewable energy: Empirical evidence across regions. *Energy Economics*, 75, 180–192. <https://doi.org/10.1016/j.eneco.2018.08.017>
- Dong, Xing, & Akhtar, N.** (2022). Nexus Between Financial Development, Renewable Energy Investment, and Sustainable Development: Role of Technical Innovations and Industrial Structure. *Frontiers in Psychology*, 13(August), 1–20. <https://doi.org/10.3389/fpsyg.2022.951162>
- Dong, Xueqin, Dong, D., & Yu, Q.** (2024). Impact of oil, gold, and energy prices on resources footprint: Evaluating the role of digital governance and financial development. *Resources Policy*, 92, 105001. <https://doi.org/10.1016/j.resourpol.2024.105001>

- Doytch, N.** (2020). The impact of foreign direct investment on the ecological footprints of nations. *Environmental and Sustainability Indicators*, 8, 100085. <https://doi.org/10.1016/j.indic.2020.100085>
- Dreher, A.** (2006). Does globalization affect growth? Evidence from a new index of globalization. *Applied Economics*, 38(10), 1091–1110. <https://doi.org/10.1080/00036840500392078>
- Drobetz, W., El Ghouli, S., Guedhami, O., & Janzen, M.** (2018). Policy uncertainty, investment, and the cost of capital. *Journal of Financial Stability*, 39, 28–45. <https://doi.org/10.1016/j.jfs.2018.08.005>
- Duodu, E., Kwarteng, E., Oteng-Abayie, E. F., & Frimpong, P. B.** (2021). Foreign direct investments and environmental quality in sub-Saharan Africa: the merits of policy and institutions for environmental sustainability. *Environmental Science and Pollution Research*, 28(46), 66101–66120. <https://doi.org/10.1007/s11356-021-15288-1>
- Dutta, A.** (2017). Oil price uncertainty and clean energy stock returns: New evidence from crude oil volatility index. *Journal of Cleaner Production*, 164, 1157–1166. <https://doi.org/10.1016/j.jclepro.2017.07.050>
- Ebaid, A., Lean, H. H., & Al-Mulali, U.** (2022). Do Oil Price Shocks Matter for Environmental Degradation? Evidence of the Environmental Kuznets Curve in GCC Countries. *Frontiers in Environmental Science*, 10(May), 1–15. <https://doi.org/10.3389/fenvs.2022.860942>
- Ebrahim, Z., Inderwildi, O. R., & King, D. A.** (2014). Macroeconomic impacts of oil price volatility: mitigation and resilience. *Frontiers in Energy*, 8(1), 9–24. <https://doi.org/10.1007/s11708-014-0303-0>
- Emenekwe, C. C., Onyeneke, R. U., & Nwajiuba, C. U.** (2022). Financial development and carbon emissions in Sub-Saharan Africa. *Environmental Science and Pollution Research*, 29(13), 19624–19641. <https://doi.org/10.1007/s11356-021-17161-7>
- Emmanuel, O. N. B., Fonchamnyo, D. C., Thierry, M. A., & Dinga, G. D.** (2023). Ecological footprint in a global perspective: the role of domestic investment, FDI, democracy and institutional quality. *Journal of Global Responsibility*, 14(4), 431–451. <https://doi.org/10.1108/JGR-09-2022-0091>
- EPA.** (2018). Inventory of U. S. Greenhouse Gas Emissions and Sinks, 1990–2018. *United States Environmental Protection Agency*.
- Erülgen, A., Rjoub, H., & Adaher, A.** (2020). Bank Characteristics Effect on Capital Structure: Evidence from PMG and CS-ARDL. *Journal of Risk and Financial Management*.
- Esmaili, P., Rafei, M., Balsalobre-Lorente, D., & Adedoyin, F. F.** (2023). The role of economic policy uncertainty and social welfare in the view of ecological footprint: evidence from the traditional and novel platform in panel ARDL approaches. *Environmental Science and Pollution Research*, 30(5), 13048–13066. <https://doi.org/10.1007/s11356-022-23044-2>
- Espoir, D., Sunge, R., & Bannor, F.** (2021). *Economic growth and CO₂ emissions: Evidence from heterogeneous panel of African countries using bootstrap Granger causality*.

- Fabrice, D., Fr, A., & Foster, A.** (2023). *Innovation and Green Development Institutional quality and green economic growth in West African economic and monetary union*. 3(March 2023). <https://doi.org/10.1016/j.igd.2023.100108>
- Falcone, P. M.** (2023). Sustainable Energy Policies in Developing Countries: A Review of Challenges and Opportunities. *Energies*, 16(18), 6682. <https://doi.org/10.3390/en16186682>
- Fang, H., Zhang, X., Lei, T., & Houadi, B. L.** (2023). FDI Quality, Green Technology Innovation and Urban Carbon Emissions: Empirical Evidence from China. *Sustainability*, 15(12), 9657. <https://doi.org/10.3390/su15129657>
- Farooq, F., Faheem, M., & Nousheen, A.** (2023). Economic Policy Uncertainty, Renewable Energy Consumption and Environmental Sustainability in China. *Pakistan Journal of Humanities and Social Sciences*, 11(2). <https://doi.org/10.52131/pjhss.2023.1102.0494>
- Fernandes, C. I., Veiga, P. M., Ferreira, J. J. M., & Hughes, M.** (2021). Green growth versus economic growth: Do sustainable technology transfer and innovations lead to an imperfect choice? *Business Strategy and the Environment*, 30(4), 2021–2037. <https://doi.org/10.1002/bse.2730>
- Fonchamnyo, D. C., Dinga, G. D., & Ngum, V. C.** (2021). Revisiting the nexus between domestic investment, foreign direct investment and external debt in SSA countries: PMG-ARDL approach. *African Development Review*, 33(3), 479–491. <https://doi.org/10.1111/1467-8268.12593>
- Food and Agriculture Organization (FAO).** (2020). *Global Forest Resources Assessment 2020* (Vol. 23, Issue 4). FAO. <https://doi.org/10.4060/ca8753en>
- Gallagher, K. P.** (2009). Economic globalization and the environment. *Annual Review of Environment and Resources*, 34, 279–304. <https://doi.org/10.1146/annurev.enviro.33.021407.092325>
- Gasparatos, A., Doll, C. N. H., Esteban, M., Ahmed, A., & Olang, T. A.** (2017). Renewable energy and biodiversity: Implications for transitioning to a Green Economy. *Renewable and Sustainable Energy Reviews*, 70(December 2015), 161–184. <https://doi.org/10.1016/j.rser.2016.08.030>
- Gokmenoglu, K., Ozatac, N., & Eren, B. M.** (2015). Relationship between Industrial Production, Financial Development and Carbon Emissions: The Case of Turkey. *Procedia Economics and Finance*, 25(May), 463–470. [https://doi.org/10.1016/s2212-5671\(15\)00758-3](https://doi.org/10.1016/s2212-5671(15)00758-3)
- Golub, S. S., Kauffmann, C., & Yeres, P.** (2011). *OECD Working Papers on International Defining and Measuring green FDI*.
- Gorji, A. A., & Martek, I.** (2023). The Role of Renewable Energy as a ‘Green Growth’ Strategy for the Built Environment. *Buildings*, 13(5), 1356. <https://doi.org/10.3390/buildings13051356>
- Goswami, A., Kapoor, H. S., Jangir, R. K., Ngigi, C. N., Nowrouzi-Kia, B., & Chattu, V. K.** (2023). Impact of Economic Growth, Trade Openness, Urbanization and Energy Consumption on Carbon Emissions: A Study of India. *Sustainability*, 15(11), 9025. <https://doi.org/10.3390/su15119025>
- Granger, C. W. J., & Yoon, G.** (2002). Hidden Cointegration. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.313831>

- Grossman, G. M., & Krueger, A. B.** (1991). *Environmental Impacts of a North American Free Trade Agreement* (Issue 3914). <https://doi.org/10.3386/w3914>
- Grossman, G. M., & Krueger, A. B.** (1995). Environmental Kuznets Curve. *The Quarterly Journal of Economics*, 110(2), 353–377.
- Grossman, G. M., & Krueger, A. B.** (2010). Economic Growth and the Environment. *Gene*, 110(2), 353–377.
- Guoyan, S., Khaskheli, A., Raza, S. A., & Shah, N.** (2022). Analyzing the association between the foreign direct investment and carbon emissions in MENA countries: a pathway to sustainable development. *Environment, Development and Sustainability*, 24(3), 4226–4243. <https://doi.org/10.1007/s10668-021-01613-8>
- Gyamfi, B. A., Bein, M. A., Udemba, E. N., & Bekun, F. V.** (2022). Renewable energy, economic globalization and foreign direct investment linkage for sustainable development in the E7 economies: revisiting the pollution haven hypothesis. *International Social Science Journal*, 72(243), 91–110. <https://doi.org/10.1111/issj.12301>
- Gygli, S., Haelg, F., Potrafke, N., & Sturm, J.-E. E.** (2019). The KOF Globalisation Index – revisited. *The Review of International Organizations*, 14(3), 543–574. <https://doi.org/10.1007/s11558-019-09344-2>
- Gyimah, J., Angela, U., Erica, N., & Opoku, O.** (2023). Promoting environmental sustainability in Africa : the position of globalization , renewable energy , and economic growth. *SN Business & Economics*. <https://doi.org/10.1007/s43546-023-00538-w>
- Habiba, U., & Xinbang, C.** (2022). The impact of financial development on CO₂ emissions: new evidence from developed and emerging countries. *Environmental Science and Pollution Research*, 29(21), 31453–31466. <https://doi.org/10.1007/s11356-022-18533-3>
- Habiba, U., Xinbang, C., & Ahmad, R. I.** (2021). The influence of stock market and financial institution development on carbon emissions with the importance of renewable energy consumption and foreign direct investment in G20 countries. *Environmental Science and Pollution Research*, 28(47), 67677–67688. <https://doi.org/10.1007/s11356-021-15321-3>
- Hamilton, J. D.** (1983). Oil and the Macroeconomy since World War II. *Journal of Political Economy*, 91(2), 228–248. <https://doi.org/10.1086/261140>
- Hao, Y., Zhang, Z. Y., Liao, H., Wei, Y. M., & Wang, S.** (2016). Is CO₂ emission a side effect of financial development? An empirical analysis for China. *Environmental Science and Pollution Research*, 23(20), 21041–21057. <https://doi.org/10.1007/s11356-016-7315-8>
- Hasan, M. M., Nan, S., & Waris, U.** (2024). Assessing the dynamics among oil consumption, ecological footprint, and renewable energy: Role of institutional quality in major oil-consuming countries. *Resources Policy*, 90, 104843. <https://doi.org/10.1016/j.resourpol.2024.104843>

- Haseeb, A., Xia, E., Danish, Baloch, M. A., & Abbas, K.** (2018). Financial development, globalization, and CO₂ emission in the presence of EKC: evidence from BRICS countries. *Environmental Science and Pollution Research*, 25(31), 31283–31296. <https://doi.org/10.1007/s11356-018-3034-7>
- Hashem Pesaran, M., & Yamagata, T.** (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, 142(1), 50–93. <https://doi.org/10.1016/j.jeconom.2007.05.010>
- Hassan, A. S.** (2021). Asymmetric effects of oil revenue on government expenditure: insights from oil-exporting developing countries. *OPEC Energy Review*, 45(2), 257–274. <https://doi.org/10.1111/opec.12203>
- Hassan, A. S., & Mhlanga, D.** (2023). The asymmetric effect of oil price on ecological footprint: evidence from oil-producing African countries. *Sustainable Energy Research*, 10(1), 16. <https://doi.org/10.1186/s40807-023-00087-8>
- Hassan Jakada, A., & Mahmood, S.** (2020). An Asymmetric Effect of Economic Growth, Foreign Direct Investment and Financial Development on the Quality of Environment in Nigeria. *The Journal of Management Theory and Practice (JMTP)*, 1(1), 5–13. <https://doi.org/10.37231/jmtp.2020.1.1.6>
- Hausman, J. A.** (1978). Specification Tests in Econometrics. *Econometrica*, 46(6), 1251–1271. <http://www.jstor.org/stable/1913827> <http://www.jstor.org/action/showPublisher?publisherCode=econosoc>
- Hosseini, H. M., & Kaneko, S.** (2013). Can environmental quality spread through institutions? *Energy Policy*, 56, 312–321. <https://doi.org/10.1016/j.enpol.2012.12.067>
- Hu, X., Yu, J., & Zhong, A.** (2022). The Asymmetric Effects of Oil Price Shocks on Green Innovation. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4291665>
- Huang, H., Ali, S., & Solangi, Y. A.** (2023). Analysis of the Impact of Economic Policy Uncertainty on Environmental Sustainability in Developed and Developing Economies. *Sustainability*, 15(7), 5860. <https://doi.org/10.3390/su15075860>
- Hunjra, A. I., Tayachi, T., Chani, M. I., Verhoeven, P., & Mehmood, A.** (2020). The moderating effect of institutional quality on the financial development and environmental quality nexus. *Sustainability (Switzerland)*, 12(9), 1–13. <https://doi.org/10.3390/su12093805>
- Huo, C., Hameed, J., Sharif, A., Albasher, G., Alamri, O., Alsultan, N., & Baig, N. ul ain.** (2022). Recent scenario and nexus of globalization to CO₂ emissions: Evidence from wavelet and Quantile on Quantile Regression approach. *Environmental Research*, 212(PA), 113067. <https://doi.org/10.1016/j.envres.2022.113067>
- Huo, W., Ullah, M. R., Zulfiqar, M., Parveen, S., & Kibria, U.** (2022). Financial Development, Trade Openness, and Foreign Direct Investment: A Battle Between the Measures of Environmental Sustainability. *Frontiers in Environmental Science*, 10(February), 1–10. <https://doi.org/10.3389/fenvs.2022.851290>

- Hussain, M., Arshad, Z., & Bashir, A.** (2022). Do economic policy uncertainty and environment - related technologies help in limiting ecological footprint? *Environmental Science and Pollution Research*, 46612–46619. <https://doi.org/10.1007/s11356-022-19000-9>
- Hussain, Z., Mehmood, B., Khan, M. K., & Tsimisaraka, R. S. M.** (2022). Green Growth, Green Technology, and Environmental Health: Evidence From High-GDP Countries. *Frontiers in Public Health*, 9(January), 1–13. <https://doi.org/10.3389/fpubh.2021.816697>
- Ibrahim, R. L., Ajide, K. B., & Omokanmi, O. J.** (2021). Non-renewable energy consumption and quality of life: Evidence from Sub-Saharan African economies. *Resources Policy*, 73, 102176. <https://doi.org/10.1016/j.resourpol.2021.102176>
- Intergovernmental Panel on Climate Change.** (2022). *mpacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* <https://www.ipcc.ch/report/ar6/wg2/>
- International Energy Agency.** (2021). *World Energy Outlook 2021.*
- IPCC.** (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Agriculture, Forestry and Other Land Use (Vol. 4).*
- Iqbal, M., Chand, S., & Ul Haq, Z.** (2022). Economic policy uncertainty and CO₂ emissions: a comparative analysis of developed and developing nations. *Environmental Science and Pollution Research*, 30(6), 15034–15043. <https://doi.org/10.1007/s11356-022-23115-4>
- Iyoboyi, M., Sabitu, A., & Okereke, S. F.** (2020). GLOBALIZATION AND ECONOMIC GROWTH IN AFRICA. *Journal of Economics and Allied Research*, 5(1), 1–19.
- Jahanger, A.** (2022). Impact of globalization on CO₂ emissions based on EKC hypothesis in developing world: the moderating role of human capital. *Environmental Science and Pollution Research*, 29(14), 20731–20751. <https://doi.org/10.1007/s11356-021-17062-9>
- Jamel, L., & Maktouf, S.** (2017). The nexus between economic growth, financial development, trade openness, and CO₂ emissions in European countries. *Cogent Economics and Finance*, 5(1). <https://doi.org/10.1080/23322039.2017.1341456>
- Javed, A., Fuinhas, J. A., & Rapposelli, A.** (2023). Asymmetric Nexus between Green Technology Innovations, Economic Policy Uncertainty, and Environmental Sustainability: Evidence from Italy. *Energies*, 16(8), 3557. <https://doi.org/10.3390/en16083557>
- Javorcik, B. S., & Wei, S.J.** (2003). Pollution Havens and Foreign Direct Investment: Dirty Secret or Popular Myth? *Contributions in Economic Analysis & Policy*, 3(2). <https://doi.org/10.2202/1538-0645.1244>
- Jiang, C., & Ma, X.** (2019). The Impact of Financial Development on Carbon Emissions: A Global Perspective. *Sustainability*, 11(19), 5241. <https://doi.org/10.3390/su11195241>

- Jiang, Y., Zhou, Z., & Liu, C.** (2019). Does economic policy uncertainty matter for carbon emission? Evidence from US sector level data. *Environmental Science and Pollution Research*, 26(24), 24380–24394. <https://doi.org/10.1007/s11356-019-05627-8>
- Jiao, Y., Xiao, X., & Bao, X.** (2022). Economic policy uncertainty, geopolitical risks, energy output and ecological footprint—Empirical evidence from China. *Energy Reports*, 8, 324–334. <https://doi.org/10.1016/j.egyr.2022.03.105>
- Jing, Y., Yajing, D., Weijie, Z., & Zongwu, C.** (2023). Economic Policy Uncertainty: Cross-Country Linkages and Spillover Effects on Economic Development in Some Belt and Road Countries. *JSystems Science and Complexity*, 36, 1169–1188. <https://doi.org/10.1007/s11424-023-1060-0>
- Johnsson, F., Kjärstad, J., & Rootzén, J.** (2019). The threat to climate change mitigation posed by the abundance of fossil fuels. *Climate Policy*, 19(2), 258–274. <https://doi.org/10.1080/14693062.2018.1483885>
- Joof, F., Samour, A., Ali, M., Tursoy, T., Haseeb, M., Hossain, M. E., & Kamal, M.** (2023). Symmetric and asymmetric effects of gold, and oil price on environment: The role of clean energy in China. *Resources Policy*, 81, 103443. <https://doi.org/10.1016/j.resourpol.2023.103443>
- Jorgenson, A., Clark, R., Kentor, J., & Rieger, A.** (2022). Networks, stocks, and climate change: A new approach to the study of foreign investment and the environment. *Energy Research & Social Science*, 87, 102461. <https://doi.org/10.1016/j.erss.2021.102461>
- Joshua, S. R., Miriam-kamah, J. R., & Oji-okoro, I.** (2022). Current Research in Environmental Sustainability Renewable energy consumption in sub-Saharan Africa (SSA): Implications on economic and environmental sustainability. *Current Research in Environmental Sustainability*, 4(March), 100129. <https://doi.org/10.1016/j.crsust.2022.100129>
- Judson, R. A., & Owen, A. L.** (1999). Estimating dynamic panel data models: A guide for macroeconomists. *Economics Letters*, 65(1), 9–15. [https://doi.org/10.1016/s0165-1765\(99\)00130-5](https://doi.org/10.1016/s0165-1765(99)00130-5)
- Kanwal, A., Khalid, S., & Alam, M. Z.** (2023). Analyzing the Asymmetric Effects of Green Finance, Financial Development and FDI on Environment Sustainability: New Insights from Pakistan Based Non-Linear ARDL Approach. *IRASD Journal of Economics*, 5(3), 625–644. <https://doi.org/10.52131/joe.2023.0503.0151>
- Kao, C.** (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, 90(1), 1–44. [https://doi.org/10.1016/S0304-4076\(98\)00023-2](https://doi.org/10.1016/S0304-4076(98)00023-2)
- Kar, S., Roy, A., & Sen, K.** (2019). The double trap: Institutions and economic development. *Economic Modelling*, 76(March 2018), 243–259. <https://doi.org/10.1016/j.econmod.2018.08.002>
- Kaufmann, D., & Kraay, A.** (2020). *The worldwide governance indicators*. The World Bank Group.

- Kelly, G. D.** (2010). Climate Change Policy: Actions and Barriers in New Zealand. *The International Journal of Climate Change: Impacts and Responses*, 2(1), 277–290. <https://doi.org/10.18848/1835-7156/CGP/v02i01/37292>
- Khan, A., Chenggang, Y., Khan, G., & Muhammad, F.** (2020). The dilemma of natural disasters: Impact on economy, fiscal position, and foreign direct investment alongside Belt and Road Initiative countries. *Science of the Total Environment*, 743, 140578. <https://doi.org/10.1016/j.scitotenv.2020.140578>
- Khan, H., Weili, L., & Khan, I.** (2022). Institutional quality, financial development and the influence of environmental factors on carbon emissions: evidence from a global perspective. *Environmental Science and Pollution Research*, 29(9), 13356–13368. <https://doi.org/10.1007/s11356-021-16626-z>
- Khan, I., Hou, F., & Le, H. P.** (2021). The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. *Science of the Total Environment*, 754, 142222. <https://doi.org/10.1016/j.scitotenv.2020.142222>
- Khan, Y., Hassan, T., Kirikkaleli, D., Xiuqin, Z., & Shukai, C.** (2022). The impact of economic policy uncertainty on carbon emissions: evaluating the role of foreign capital investment and renewable energy in East Asian economies. *Environmental Science and Pollution Research*, 29(13), 18527–18545. <https://doi.org/10.1007/s11356-021-17000-9>
- Khan, Z., Ali, S., Umar, M., Kirikkaleli, D., & Jiao, Z.** (2020). Consumption-based carbon emissions and International trade in G7 countries: The role of Environmental innovation and Renewable energy. *Science of the Total Environment*, 730, 138945. <https://doi.org/10.1016/j.scitotenv.2020.138945>
- Khurshid, A., Huang, Y., Khan, K., & Cifuentes-Faura, J.** (2024). Innovation, institutions, and sustainability: Evaluating drivers of household green technology adoption and environmental sustainability of Africa. *Gondwana Research*, 132, 88–102. <https://doi.org/10.1016/j.gr.2024.03.012>
- Kim, S.-E., & Seok, J. H.** (2023). The impact of foreign direct investment on CO 2 emissions considering economic development: Evidence from South Korea. *The Journal of International Trade & Economic Development*, 32(4), 537–552. <https://doi.org/10.1080/09638199.2022.2122538>
- Kong, Q., Li, R., Wang, Z., & Peng, D.** (2022). Economic policy uncertainty and firm investment decisions: Dilemma or opportunity? *International Review of Financial Analysis*, 83, 102301. <https://doi.org/10.1016/j.irfa.2022.102301>
- Kwabena, T. D., Danso-Mensah, K., & Bokpin, G. A.** (2017). The environmental effects of economic growth and globalization in Sub-Saharan Africa: A panel general method of moments approach. *Research in International Business and Finance*, 42(October 2016), 939–949. <https://doi.org/10.1016/j.ribaf.2017.07.028>
- Lamb, W. F., & Minx, J. C.** (2020). The political economy of national climate policy: Architectures of constraint and a typology of countries. *Energy Research & Social Science*, 64, 101429. <https://doi.org/10.1016/j.erss.2020.101429>

- Lardic, S., & Mignon, V.** (2006). The impact of oil prices on GDP in European countries: An empirical investigation based on asymmetric cointegration. *Energy Policy*, 34(18), 3910–3915. <https://doi.org/10.1016/j.enpol.2005.09.019>
- Laurent, A., Olsen, S. I., & Hauschild, M. Z.** (2012). Limitations of Carbon Footprint as Indicator of Environmental Sustainability. *Environmental Science & Technology*, 46(7), 4100–4108. <https://doi.org/10.1021/es204163f>
- Le, H. P., & Ozturk, I.** (2020). The impacts of globalization, financial development, government expenditures, and institutional quality on CO₂ emissions in the presence of environmental Kuznets curve. *Environmental Science and Pollution Research*, 27(18), 22680–22697. <https://doi.org/10.1007/s11356-020-08812-2>
- Le, H. P., & Van, D. T. B.** (2020). The energy consumption structure and African EMDEs' sustainable development. *Heliyon*, 6(4), e03822. <https://doi.org/10.1016/j.heliyon.2020.e03822>
- Leal, W., Franziska, F., Amanda, W., Salvia, L., Beynaghi, A., Shulla, K., Kovaleva, M., & Vasconcelos, C. R. P.** (2020). Discover Sustainability Heading towards an unsustainable world : some of the implications of not achieving the SDGs. *Discover Sustainability*. <https://doi.org/10.1007/s43621-020-00002-x>
- Levine, R.** (1997). Financial Development and Economic Growth: Views and Agenda. *Journal of Economic Literature*, 35(2), 688–726.
- Li, F., Chang, T., Wang, M. C., & Zhou, J.** (2022). The relationship between health expenditure, CO₂ emissions, and economic growth in the BRICS countries—based on the Fourier ARDL model. *Environmental Science and Pollution Research*, 29(8), 10908–10927. <https://doi.org/10.1007/s11356-021-17900-w>
- Li, J., & Huang, S.** (2021). The dynamic relationship between economic policy uncertainty and substantial economic growth in China. *Marine Economics and Management*, 4(2), 113–134. <https://doi.org/10.1108/maem-04-2021-0003>
- Li, K., Fang, L., & He, L.** (2020). The impact of energy price on CO₂ emissions in China: A spatial econometric analysis. *Science of The Total Environment*, 706, 135942. <https://doi.org/10.1016/j.scitotenv.2019.135942>
- Li, R., Wang, Q., & Li, L.** (2023). Does renewable energy reduce per capita carbon emissions and per capita ecological footprint? New evidence from 130 countries. *Energy Strategy Reviews*, 49, 101121. <https://doi.org/10.1016/j.esr.2023.101121>
- Li, X., Hu, Z., & Zhang, Q.** (2021). Environmental regulation, economic policy uncertainty, and green technology innovation. *Clean Technologies and Environmental Policy*, 23(10), 2975–2988. <https://doi.org/10.1007/s10098-021-02219-4>
- Li, Ying, & Li, S.** (2021). The Influence Study on Environmental Regulation and Green Total Factor Productivity of China's Manufacturing Industry. *Discrete Dynamics in Nature and Society*, 2021. <https://doi.org/10.1155/2021/5580414>
- Li, Yiying, Ren, X., & Taghizadeh-Hesary, F.** (2023). Vulnerability of sustainable markets to fossil energy shocks. *Resources Policy*, 85, 103879. <https://doi.org/10.1016/j.resourpol.2023.103879>
- Liao, Y., Loures, E. R., Deschamps, F., Brezinski, G., & Venâncio, A.** (2018). The impact of the fourth industrial revolution: A cross-country/region comparison. *Production*, 28. <https://doi.org/10.1590/0103-6513.20180061>

- Liu, H., Wang, K. T., Khudoykulov, K., Tai, T. D., Ngo, T. Q., & Phan, T. T. H.** (2022). Does Economic Development Impact CO₂ Emissions and Energy Efficiency Performance? Fresh Evidences From Europe. *Frontiers in Energy Research*, 10(April), 1–11. <https://doi.org/10.3389/fenrg.2022.860427>
- Liu, M., Ren, X., Cheng, C., & Wang, Z.** (2020). The role of globalization in CO₂ emissions: A semi-parametric panel data analysis for G7. *Science of the Total Environment*, 718, 137379. <https://doi.org/10.1016/j.scitotenv.2020.137379>
- Liu, P., Ur Rahman, Z., Józwiak, B., & Doğan, M.** (2024). Determining the environmental effect of Chinese FDI on the Belt and Road countries CO₂ emissions: an EKC-based assessment in the context of pollution haven and halo hypotheses. *Environmental Sciences Europe*, 36(1), 48. <https://doi.org/10.1186/s12302-024-00866-0>
- Liu, Y., & Zhang, Z.** (2022). How does economic policy uncertainty affect CO₂ emissions? A regional analysis in China. *Environmental Science and Pollution Research*, 29(3), 4276–4290. <https://doi.org/10.1007/s11356-021-15936-6>
- Ly-My, D., Le, T., & Park, D.** (2024). Foreign direct investment (FDI) and environmental quality: Is greenfield FDI greener than mergers and acquisitions FDI? *The World Economy*, 47(5), 1827–1850. <https://doi.org/10.1111/twec.13513>
- Maduka, A. C., Ogwu, S. O., & Ekesiobi, C. S.** (2022). Assessing the moderating effect of institutional quality on economic growth—carbon emission nexus in Nigeria. *Environmental Science and Pollution Research*, 29(43), 64924–64938. <https://doi.org/10.1007/s11356-022-20346-3>
- Madzianike, Y. M.** (2024). The dynamic relationship between foreign direct investment and carbon emissions in southern Africa and west Africa regions: The intervening role of financial development. *EPRA International Journal of Economic Growth and Environmental Issues*, 24–41. <https://doi.org/10.36713/epra15806>
- Mahadevan, R., & Sun, Y.** (2020). Effects of foreign direct investment on carbon emissions: Evidence from China and its Belt and Road countries. *Journal of Environmental Management*, 276, 111321. <https://doi.org/10.1016/j.jenvman.2020.111321>
- Mahjabeen, Shah, S. Z. A., Chughtai, S., & Simonetti, B.** (2020). Renewable energy, institutional stability, environment and economic growth nexus of D-8 countries. In *Energy Strategy Reviews* (Vol. 29). Elsevier Ltd. <https://doi.org/10.1016/j.esr.2020.100484>
- Mahmood, H., Alkhateeb, T. T. Y., & Furqan, M.** (2020a). Oil sector and CO₂ emissions in Saudi Arabia: asymmetry analysis. *Palgrave Communications*, 6(1), 88. <https://doi.org/10.1057/s41599-020-0470-z>
- Mahmood, H., Alkhateeb, T. T. Y., & Furqan, M.** (2020b). Industrialization, urbanization and CO₂ emissions in Saudi Arabia: Asymmetry analysis. *Energy Reports*, 6, 1553–1560. <https://doi.org/10.1016/j.egy.2020.06.004>

- Maji, I. K., Habibullah, M. S., Saari, M. Y., & Abdul-Rahim, A. S.** (2017). The nexus between energy price changes and environmental quality in Malaysia. *Energy Sources, Part B: Economics, Planning, and Policy*, 12(10), 903–909. <https://doi.org/10.1080/15567249.2017.1323052>
- Malik, M. Y., Latif, K., Khan, Z., Butt, H. D., Hussain, M., & Nadeem, M. A.** (2020). Symmetric and asymmetric impact of oil price, FDI and economic growth on carbon emission in Pakistan: Evidence from ARDL and non-linear ARDL approach. *Science of The Total Environment*, 726, 138421. <https://doi.org/10.1016/j.scitotenv.2020.138421>
- Mansour, N.** (2023). Green Technology Innovation and Financial Services System: Evidence from China. *Businesses*, 3(1), 98–113. <https://doi.org/10.3390/businesses3010008>
- Maplecroft.** (2011). *Climate Change Vulnerability Index 2012*. <https://www.maplecroft.com/risk-indices/climate-change-vulnerability-index/>
- Mehdi, B. J., & Slim, B. Y.** (2017). The role of renewable energy and agriculture in reducing CO₂ emissions: Evidence for North Africa countries. *Ecological Indicators*, 74, 295–301. <https://doi.org/10.1016/j.ecolind.2016.11.032>
- Mehmood, U., & Tariq, S.** (2020). Globalization and CO₂ emissions nexus: evidence from the EKC hypothesis in South Asian countries. *Environmental Science and Pollution Research*, 27(29), 37044–37056. <https://doi.org/10.1007/s11356-020-09774-1>
- Menegaki, A. N.** (2011). Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. *Energy Economics*, 33(2), 257–263. <https://doi.org/10.1016/j.eneco.2010.10.004>
- Meng, K., Khan, M. N., Adebayo, T. S., & Olanrewaju, V. O.** (2024). How do oil price uncertainty and economic policy uncertainty influence achievement of net-zero emissions targets by 2050? A quantile-based analysis. *International Journal of Sustainable Development & World Ecology*, 31(7), 892–911. <https://doi.org/10.1080/13504509.2024.2344860>
- Mensah, I. A., Sun, M., Gao, C., Omari-Sasu, A. Y., Zhu, D., Ampimah, B. C., & Quarcoo, A.** (2019). Analysis on the nexus of economic growth, fossil fuel energy consumption, CO₂ emissions and oil price in Africa based on a PMG panel ARDL approach. *Journal of Cleaner Production*, 228, 161–174. <https://doi.org/10.1016/j.jclepro.2019.04.281>
- Merko, F., Xhakolli, E., Merko, F., Themelko, H., & Merko, F.** (2019). The Importance of Calculating Green Gdp in Economic Growth of a Country – Case Study Albania. *International Journal of Ecosystems and Ecology Science (IJEES)*, 9(3), 469–474. <https://doi.org/10.31407/ijeess9308>
- Miamo, C. W., & Achuo, E. D.** (2021). Crude Oil Price and Real GDP Growth: An Application of ARDL Bounds Cointegration and Toda-Yamamoto Causality Tests. *Economics Bulletin*, 41(3), 1615–1626.

- Mitić, P., Fedajev, A., Radulescu, M., & Rehman, A.** (2023). The relationship between CO₂ emissions, economic growth, available energy, and employment in SEE countries. *Environmental Science and Pollution Research*, 30(6), 16140–16155. <https://doi.org/10.1007/s11356-022-23356-3>
- Mohamed, M. M. A., Liu, P., & Nie, G.** (2022). Causality between Technological Innovation and Economic Growth: Evidence from the Economies of Developing Countries. *Sustainability (Switzerland)*, 14(6), 1–39. <https://doi.org/10.3390/su14063586>
- Mujtaba, A., & Jena, P. K.** (2021). Analyzing asymmetric impact of economic growth, energy use, FDI inflows, and oil prices on CO₂ emissions through NARDL approach. *Environmental Science and Pollution Research*, 28(24), 30873–30886. <https://doi.org/10.1007/s11356-021-12660-z>
- Mumuni, S., & Mwimba, T.** (2022). Modeling the impact of green energy consumption and natural resources rents on economic growth in Africa: An analysis of dynamic panel ARDL and the feasible generalized least squares estimators. *Cogent Economics & Finance*. <https://doi.org/10.1080/23322039.2022.2161774>
- Mustapha, A. B., Malah, B. J., & Daluma, M. S.** (2018). Institutions and Resource Allocation Towards Understanding Economic Efficiency. *African Journal of Management*, 2(1), 201–202.
- Nahrin, R., Rahman, M. H., Majumder, S. C., & Esquivias, M. A.** (2023). Economic Growth and Pollution Nexus in Mexico, Colombia, and Venezuela (G-3 Countries): The Role of Renewable Energy in Carbon Dioxide Emissions. *Energies*, 16(3). <https://doi.org/10.3390/en16031076>
- Nakhli, M. S., Shahbaz, M., Jebli, M. Ben, Ben Jebli, M., & Wang, S.** (2022). Nexus between economic policy uncertainty, renewable & non-renewable energy and carbon emissions: Contextual evidence in carbon neutrality dream of USA. *Renewable Energy*, 185, 75–85. <https://doi.org/10.1016/j.renene.2021.12.046>
- Nguyen-Thanh, N., Chin, K.-H., & Nguyen, V.** (2022). Does the pollution halo hypothesis exist in this “better” world? The evidence from STIRPAT model. *Environmental Science and Pollution Research*, 29(58), 87082–87096. <https://doi.org/10.1007/s11356-022-21654-4>
- Obobisa, E. S., Chen, H., Ayamba, E. C., & Nyarko Mensah, C.** (2021). The Causal Relationship Between China-Africa Trade, China OFDI, and Economic Growth of African Countries. *SAGE Open*, 11(4). <https://doi.org/10.1177/21582440211064899>
- Obobisa, E. S., Chen, H., & Mensah, I. A.** (2022). The impact of green technological innovation and institutional quality on CO₂ emissions in African countries. *Technological Forecasting and Social Change*, 180, 121670. <https://doi.org/10.1016/j.techfore.2022.121670>
- Odhiambo, N. M.** (2020). Financial development, income inequality and carbon emissions in sub-Saharan African countries: A panel data analysis. *Energy Exploration and Exploitation*, 38(5), 1914–1931. <https://doi.org/10.1177/0144598720941999>

- OECD.** (2020). Towards Green Growth. In *OECD* (OECD Green Growth Studies). OECD. <https://doi.org/10.1787/9789264101630-3-en>
- Ofori, I. K., Gbolonyo, E. Y., & Ojong, N.** (2023). Foreign direct investment and inclusive green growth in Africa: Energy efficiency contingencies and thresholds. *Energy Economics*, *117*(July 2022), 106414. <https://doi.org/10.1016/j.eneco.2022.106414>
- Okwanya, I., Abah, P. O., Amaka, E.-O. G., Ozturk, I., Alhassan, A., & Bekun, F. V.** (2023). Does carbon emission react to oil price shocks? Implications for sustainable growth in Africa. *Resources Policy*, *82*, 103610. <https://doi.org/10.1016/j.resourpol.2023.103610>
- Olanrele, I., & Awode, S.** (2022). Assessing the Nexus among Energy Consumption, Foreign Direct Investment and Economic Growth in Sub-Saharan Africa. *Central Bank of Nigeria Journal of Applied Statistics*, *13*(1). <https://doi.org/10.33429/Cjas.13122.2/9>
- Olubusoye, O. E., & Musa, D.** (2020). Carbon Emissions and Economic Growth in Africa: Are They Related? *Cogent Economics and Finance*, *8*(1). <https://doi.org/10.1080/23322039.2020.1850400>
- Onifade, S. T.** (2023). Environmental impacts of energy indicators on ecological footprints of oil-exporting African countries: Perspectives on fossil resources abundance amidst sustainable development quests. *Resources Policy*, *82*(February), 103481. <https://doi.org/10.1016/j.resourpol.2023.103481>
- Onofrei, M., Vatamanu, A. F., & Cigu, E.** (2022). The Relationship Between Economic Growth and CO₂ Emissions in EU Countries: A Cointegration Analysis. *Frontiers in Environmental Science*, *10*(July), 1–11. <https://doi.org/10.3389/fenvs.2022.934885>
- Oryani, B., Moridian, A., Rezania, S., Vasseghian, Y., Bagheri, M., & Shahzad, K.** (2022). Asymmetric impacts of economic uncertainties and energy consumption on the ecological Footprint: Implications apropos structural transformation in South Korea. *Fuel*, *322*(April), 124180. <https://doi.org/10.1016/j.fuel.2022.124180>
- Osadume, R., & University, E. O.** (2021). Impact of economic growth on carbon emissions in selected West African countries, 1980–2019. *Journal of Money and Business*, *1*(1), 8–23. <https://doi.org/10.1108/jmb-03-2021-0002>
- Osei-Kusi, F., Wu, C., Tetteh, S., & Castillo, W. I. G.** (2024). The dynamics of carbon emissions, energy, income, and life expectancy: Regional comparative analysis. *PLOS ONE*, *19*(2), e0293451. <https://doi.org/10.1371/journal.pone.0293451>
- Ouoba, Y.** (2017). CO₂ Emissions and Economic Growth in the West African Economic and Monetary Union (WAEMU) Countries. *Environmental Management and Sustainable Development*, *6*(2), 174. <https://doi.org/10.5296/emsd.v6i2.11145>
- Panayotou, T.** (2000). Globalization and Environment. In *CID Working Paper Series 2000.53* (Vol. 41, Issue 1). <https://doi.org/10.1177/001088040004100116>

- Paramati, S. R., Alam, M. S., & Apergis, N.** (2018). The role of stock markets on environmental degradation: A comparative study of developed and emerging market economies across the globe. *Emerging Markets Review*, 35, 19–30. <https://doi.org/10.1016/j.ememar.2017.12.004>
- Pata, U. K., & Karlilar Pata, S.** (2024). Towards sustainable development in African countries: Are modern and combustible renewable energies effective? *Sustainable Development*. <https://doi.org/10.1002/sd.3040>
- Pedroni, P.** (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, 0305–9049.
- Pesaran, M. H.** (1998). An Autoregressive Distributed-Lag Modelling Approach to Cointegration Analysis. In *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium* (pp. 371–413). Cambridge University Press. <https://doi.org/10.1017/CCOL0521633230.011>
- Pesaran, M. H.** (2007a). A simple panel unit root test in the presence of cross-section dependence. *Journal of applied econometrics*, 21(August 2012), 1–21. <https://doi.org/10.1002/jae>
- Pesaran, M. H.** (2007b). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, 22(2), 265–312. <https://doi.org/10.1002/jae.951>
- Pesaran, M. H.** (2015). Testing Weak Cross-Sectional Dependence in Large Panels. *Econometric Reviews*, 34(6–10), 1089–1117. <https://doi.org/10.1080/07474938.2014.956623>
- Pesaran, M. H.** (2020). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, 60(1), 13–50. <https://doi.org/10.1007/s00181-020-01875-7>
- Pesaran, M. H., Shin, Y., & Smith, R. P.** (1999). Pooled Mean Group Estimation of Dynamic Heterogeneous Panels. *Journal of the American Statistical Association*, 94(446), 621–634. <https://doi.org/10.1080/01621459.1999.10474156>
- Pesaran, M. H., & Smith, R.** (1995). Econometrics Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics*, 68, 79–113.
- Pirgaip, B., & Dinçergök, B.** (2020). Economic policy uncertainty, energy consumption and carbon emissions in G7 countries: evidence from a panel Granger causality analysis. *Environmental Science and Pollution Research*, 27(24), 30050–30066. <https://doi.org/10.1007/s11356-020-08642-2>
- Porter, M. E., & Van Der Linde, C.** (1995). American Economic Association Toward a New Conception of the Environment-Competitiveness Relationship. *Source: The Journal of Economic Perspectives*, 9(4), 97–118. <http://www.jstor.org/stable/2138392>
- Qamri, G. M., Sheng, B., Adeel-Farooq, R. M., & Alam, G. M.** (2022). The criticality of FDI in Environmental Degradation through financial development and economic growth: Implications for promoting the green sector. *Resources Policy*, 78, 102765. <https://doi.org/10.1016/j.resourpol.2022.102765>

- Rahman, H., Voumik, L. C., & Majumder, S. C.** (2022). *Scrutinizing the Existence of the Environmental Kuznets Curve in the Context of Foreign Direct Investment, Trade and Renewable Energy in Bangladesh: Impending from ARDL Method.* 0–14. <https://doi.org/10.21203/rs.3.rs-1930773/v1>
- Rasheed, M. Q., Haseeb, A., Adebayo, T. S., Ahmed, Z., & Ahmad, M.** (2022). The long-run relationship between energy consumption, oil prices, and carbon dioxide emissions in European countries. *Environmental Science and Pollution Research*, 29(16), 24234–24247. <https://doi.org/10.1007/s11356-021-17601-4>
- Rehman, S. U., Kraus, S., Shah, S. A., Khanin, D., & Mahto, R. V.** (2021). Analyzing the relationship between green innovation and environmental performance in large manufacturing firms. *Technological Forecasting and Social Change*, 163, 120481. <https://doi.org/10.1016/j.techfore.2020.120481>
- Romer, P.** (1994). The origins of endogenous growth. *The Journal of Economic Perspectives*, 8(1), 3–22. <https://doi.org/10.4324/9780203443965.ch26>
- Roodman, D.** (2009). How to do xtabond2: An introduction to difference and system GMM in Stata. *Stata Journal*, 9(1), 86–136. <https://doi.org/10.1177/1536867x0900900106>
- Roy, A.** (2024). The impact of foreign direct investment, renewable and non-renewable energy consumption, and natural resources on ecological footprint: an Indian perspective. *International Journal of Energy Sector Management*, 18(1), 141–161. <https://doi.org/10.1108/IJESM-09-2022-0004>
- Saboori, B., Al-mulali, U., Bin Baba, M., & Mohammed, A. H.** (2016). Oil-Induced environmental Kuznets curve in organization of petroleum exporting countries (OPEC). *International Journal of Green Energy Oil-Induced Environmental Kuznets Curve in Organization of Petroleum Exporting Countries (OPEC)*, 13(4), 408–416. <https://doi.org/10.1080/15435075.2014.961468>
- Sadorsky, P.** (2010). The impact of financial development on energy consumption in emerging economies. *Energy Policy*, 38(5), 2528–2535. <https://doi.org/10.1016/j.enpol.2009.12.048>
- Sahoo, M., & Sahoo, J.** (2022). Effects of renewable and non-renewable energy consumption on CO₂ emissions in India: Empirical evidence from disaggregated data analysis. *Journal of Public Affairs*, 22(1). <https://doi.org/10.1002/pa.2307>
- Salman, M., Long, X., Dauda, L., & Mensah, C. N.** (2019). The impact of institutional quality on economic growth and carbon emissions: Evidence from Indonesia, South Korea and Thailand. *Journal of Cleaner Production*, 241, 118331. <https://doi.org/10.1016/j.jclepro.2019.118331>
- Sarkodie, S. A., Strezov, V., Weldekidan, H., Asamoah, E. F., Owusu, P. A., & Doyi, I. N. Y.** (2019). Environmental sustainability assessment using dynamic Autoregressive-Distributed Lag simulations—Nexus between greenhouse gas emissions, biomass energy, food and economic growth. *Science of the Total Environment*, 668, 318–332. <https://doi.org/10.1016/j.scitotenv.2019.02.432>
- Selmeý, M. G., & Elamer, A. A.** (2023). Economic policy uncertainty, renewable energy and environmental degradation: Evidence from Egypt. *Environmental Science and Pollution Research*, 30(20), 58603–58617. <https://doi.org/10.1007/s11356-023-26426-2>

- Shabir, M., Ali, M., Hashmi, S. H., & Bakhsh, S.** (2022). Heterogeneous effects of economic policy uncertainty and foreign direct investment on environmental quality: cross-country evidence. *Environmental Science and Pollution Research*, 29(2), 2737–2752. <https://doi.org/10.1007/s11356-021-15715-3>
- Shahbaz, M., Balsalobre, D., & Shahzad, S. J. H.** (2019). The Influencing Factors of CO₂ Emissions and the Role of Biomass Energy Consumption: Statistical Experience from G-7 Countries. *Environmental Modeling and Assessment*, 24(2), 143–161. <https://doi.org/10.1007/s10666-018-9620-8>
- Shahbaz, M., Kumar Tiwari, A., & Nasir, M.** (2011). The effects of financial development, economic growth, coal consumption and trade openness on CO₂ emissions in South Africa. In *Energy Policy* (Vol. 61, Issue 32723). Elsevier. <https://doi.org/10.1016/j.enpol.2013.07.006>
- Shahbaz, M., & Lean, H. H.** (2012). Does financial development increase energy consumption? The role of industrialization and urbanization in Tunisia. *Energy Policy*, 40(1), 473–479. <https://doi.org/10.1016/j.enpol.2011.10.050>
- Shahbaz, M., Mallick, H., Mahalik, M. K., & Loganathan, N.** (2015). Does globalization impede environmental quality in India? *Ecological Indicators*, 52, 379–393. <https://doi.org/10.1016/j.ecolind.2014.12.025>
- Shahbaz, M., Nasir, M. A., & Roubaud, D.** (2018). Environmental degradation in France: The effects of FDI, financial development, and energy innovations. *Energy Economics*, 74, 843–857. <https://doi.org/10.1016/j.eneco.2018.07.020>
- Shahbaz, M., Nasreen, S., Abbas, F., & Anis, O.** (2015). Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? *Energy Economics*, 51, 275–287. <https://doi.org/10.1016/j.eneco.2015.06.014>
- Shahbaz, M., Shahzad, S. J. H., Mahalik, M. K., & Hammoudeh, S.** (2017). Does Globalisation Worsen Environmental Quality in Developed Economies? *Environmental Modeling and Assessment*, 23(2), 141–156. <https://doi.org/10.1007/s10666-017-9574-2>
- Shahbaz, M., Solarin, S. A., & Ozturk, I.** (2016). Environmental Kuznets Curve hypothesis and the role of globalization in selected African countries. *Ecological Indicators*, 67, 623–636. <https://doi.org/10.1016/j.ecolind.2016.03.024>
- Shepard, D.** (2019). *Global warming: severe consequences for Africa: new report projects greater temperature increases*. <https://doi.org/10.18356/98ededc9-en>
- Shikwambana, L., Mhangara, P., & Kganyago, M.** (2021). Assessing the relationship between economic growth and emissions levels in south africa between 1994 and 2019. *Sustainability (Switzerland)*, 13(5), 1–15. <https://doi.org/10.3390/su13052645>
- Shin, Y., Yu, B., & Greenwood-nimmo, M.** (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In R. C. Sickles & W. C. Horrace (Eds.), *Festschrift in honor of Peter Schmidt: Econometric methods and applications* (pp. 281–314). Springer New York. <https://doi.org/10.1007/978-1-4899-8008-3>

- Shoib, H. M., Rafique, M. Z., Nadeem, A. M., & Huang, S.** (2020). Impact of financial development on CO₂ emissions: A comparative analysis of developing countries (D8) and developed countries (G8). *Environmental Science and Pollution Research*, 27(11), 12461–12475. <https://doi.org/10.1007/s11356-019-06680-z>
- Singhania, M., & Saini, N.** (2021). Demystifying pollution haven hypothesis: Role of FDI. *Journal of Business Research*, 123, 516–528. <https://doi.org/10.1016/j.jbusres.2020.10.007>
- Sohag, K., Kalugina, O., & Samargandi, N.** (2019). Re-visiting environmental Kuznets curve: role of scale, composite, and technology factors in OECD countries. *Environmental Science and Pollution Research*, 26(27), 27726–27737. <https://doi.org/10.1007/s11356-019-05965-7>
- Sperling, F., Granoff, I., & Vygas, Y.** (2012). Facilitating Green Growth in Africa: Perspectives From the African Development Bank. In *Discussion Paper* (Issue June).
- Ssali, M. W., Du, J., Mensah, I. A., & Hongo, D. O.** (2019). RETRACTED ARTICLE: Investigating the nexus among environmental pollution, economic growth, energy use, and foreign direct investment in 6 selected sub-Saharan African countries. *Environmental Science and Pollution Research*, 26(11), 11245–11260. <https://doi.org/10.1007/s11356-019-04455-0>
- Statista.** (2021). *Carbon dioxide emissions worldwide from 1965 to 2020, by region*. Retrieved from. <https://www.statista.com/statistics/205966/world-carbon-dioxide-emissions-by-region/#professional>
- Steckel, J. C., Hilaire, J., Jakob, M., & Edenhofer, O.** (2020). Coal and carbonization in sub-Saharan Africa. *Nature Climate Change*, 10(1), 83–88. <https://doi.org/10.1038/s41558-019-0649-8>
- Svirydzenka, K.** (2016). Introducing a New Broad-based Index of Financial Development. In *IMF Working Papers* (Vol. 16, Issue 05). <https://doi.org/10.5089/9781513583709.001>
- Syed, A. A., & Tripathi, R.** (2018). Impact of economic growth and population dynamics on CO₂ emissions: Study of developing nations. *Indian Journal of Environmental Protection*, 38(6), 495–505.
- Syed, Q. R., & Bouri, E.** (2022). Impact of economic policy uncertainty on CO₂ emissions in the US: Evidence from bootstrap ARDL approach. *Journal of Public Affairs*, 22(3), 1–9. <https://doi.org/10.1002/pa.2595>
- Tabash, M. I., Farooq, U., Al-Absy, M. S. M., Albzour, O. F., & Mahmoud, O. A.** (2023). How does economic policy uncertainty influence the innovation activities: Empirical evidence from BRICS. *Journal of Open Innovation: Technology, Market, and Complexity*, 9(4), 100164. <https://doi.org/10.1016/j.joitmc.2023.100164>
- Tamazian, A., Chousa, J. P., & Vadlamannati, K. C.** (2009). Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries. *Energy Policy*, 37(1), 246–253. <https://doi.org/10.1016/j.enpol.2008.08.025>

- Tawiah, V., Zakari, A., & Adedoyin, F. F.** (2021). Determinants of green growth in developed and developing countries. *Environmental Science and Pollution Research*, 39227–39242.
- Teklie, D. K., & Yağmur, M. H.** (2024). Effect of Economic Growth on CO₂ Emission in Africa: Do Financial Development and Globalization Matter? *International Journal of Energy Economics and Policy*, 14(1), 121–140. <https://doi.org/10.32479/ijeep.15141>
- Thombs, R. P.** (2017). The Paradoxical Relationship between Renewable Energy and Economic Growth: A Cross-National Panel Study, 1990-2013. *Journal of World-Systems Research*, 23(2), 540–564. <https://doi.org/10.5195/jwsr.2017.711>
- Tiba, S., & Belaid, F.** (2020). The pollution concern in the era of globalization: Do the contribution of foreign direct investment and trade openness matter? *Energy Economics*, 92. <https://doi.org/10.1016/j.eneco.2020.104966>
- Tsaurai, K.** (2019). The impact of financial development on carbon dioxide emissions in Africa. *International Journal of Energy Economics and Policy*, 29(17), 25902–25915. <https://doi.org/10.1007/s11356-021-17519-x>
- Tsoy, L., & Heshmati, A.** (2023). Is FDI inflow bad for environmental sustainability? *Environment, Development and Sustainability*, 26(11), 28843–28858. <https://doi.org/10.1007/s10668-023-03844-3>
- Twerefou, D. K., Adusah-Poku, F., & Bekoe, W.** (2016). An empirical examination of the Environmental Kuznets Curve hypothesis for carbon dioxide emissions in Ghana: an ARDL approach. *Environmental & Socio-Economic Studies*, 4(4), 1–12. <https://doi.org/10.1515/environ-2016-0019>
- Udeagha, M. C., & Muchapondwa, E.** (2022). Investigating the moderating role of economic policy uncertainty in environmental Kuznets curve for South Africa: Evidence from the novel dynamic ARDL simulations approach. *Environmental Science and Pollution Research*, 29(51), 77199–77237. <https://doi.org/10.1007/s11356-022-21107-y>
- Udejaja, E. A., & Isah, K. O.** (2022). Stock markets ' reaction to COVID-19 : Analyses of countries with high incidence of cases / deaths in Africa. *Scientific African*, 15, e01076. <https://doi.org/10.1016/j.sciaf.2021.e01076>
- Ulucak, R., & Bilgili, F.** (2018). A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. *Journal of Cleaner Production*, 188, 144–157. <https://doi.org/10.1016/j.jclepro.2018.03.191>
- UNCTAD.** (2021). *United Nations Conference on Trade and Development*.
- UNFCCC.** (2015). *The paris agreement; Towards a Climate-Neutral Europe: Curbing the Trend*. <https://doi.org/10.4324/9789276082569-2>
- United Nations Economic Commission for Africa (UNECA).** (2021). *Africa's trade and development report 2021: Towards a sustainable future*.
- Vaghefi, N., Siwar, C., & Aziz, S.** (2015). Green GDP and Sustainable Development in Malaysia. *Current World Environment*, 10(1), 01–08. <https://doi.org/10.12944/cwe.10.1.01>

- Van Tran, H., Tran, A. V., Bui Hoang, N., & Mai, T. N. H.** (2024). Asymmetric effects of foreign direct investment and globalization on ecological footprint in Indonesia. *PLOS ONE*, *19*(1), e0297046. <https://doi.org/10.1371/journal.pone.0297046>
- Venkatraja, B.** (2020). Does renewable energy affect economic growth? Evidence from panel data estimation of BRIC countries. *International Journal of Sustainable Development and World Ecology*, *27*(2), 107–113. <https://doi.org/10.1080/13504509.2019.1679274>
- Wada, I., Faizulayev, A., & Victor Bekun, F.** (2021). Exploring the role of conventional energy consumption on environmental quality in Brazil: Evidence from cointegration and conditional causality. *Gondwana Research*, *98*, 244–256. <https://doi.org/10.1016/j.gr.2021.06.009>
- Wang, C., & Uctum, M.** (2024). Ecological footprint of FDI inflows and income threshold effect: New results with a new approach to income classification. *Environmental and Sustainability Indicators*, *22*, 100356. <https://doi.org/10.1016/j.indic.2024.100356>
- Wang, H., Dong, C., & Liu, Y.** (2019). Beijing direct investment to its neighbors: A pollution haven or pollution halo effect? *Journal of Cleaner Production*, *239*, 118062. <https://doi.org/10.1016/j.jclepro.2019.118062>
- Wang, L., Vo, X. V., Shahbaz, M., & Ak, A.** (2020). Globalization and carbon emissions: Is there any role of agriculture value-added, financial development, and natural resource rent in the aftermath of COP21? *Journal of Environmental Management*, *268*(March), 110712. <https://doi.org/10.1016/j.jenvman.2020.110712>
- Wang, M., Zhang, X., & Hu, Y.** (2021). The green spillover effect of the inward foreign direct investment: Market versus innovation. *Journal of Cleaner Production*, *328*, 129501. <https://doi.org/10.1016/j.jclepro.2021.129501>
- Wang, Qiang, Wang, X., & Li, R.** (2022). Does urbanization redefine the environmental Kuznets curve? An empirical analysis of 134 Countries. *Sustainable Cities and Society*, *76*, 103382. <https://doi.org/10.1016/j.scs.2021.103382>
- Wang, Qing, Xiao, K., & Lu, Z.** (2020). Does economic policy uncertainty affect CO₂ emissions? Empirical evidence from the United States. *Sustainability*, *12*(21), 1–11. <https://doi.org/10.3390/su12219108>
- Wang, S., Wang, H., & Sun, Q.** (2020). The Impact of Foreign Direct Investment on Environmental Pollution in China: Corruption Matters. *International Journal of Environmental Research and Public Health*, *17*(18), 6477. <https://doi.org/10.3390/ijerph17186477>
- Wang, Zhou, T., Chen, H., & Rong, Z.** (2019). Environmental homogenization or heterogenization? The effects of globalization on carbon dioxide emissions, 1970-2014. *Sustainability (Switzerland)*, *11*(10), 13–15. <https://doi.org/10.3390/su11102752>

- Wei, S., Jiandong, W., & Saleem, H.** (2023). The impact of renewable energy transition, green growth, green trade and green innovation on environmental quality: Evidence from top 10 green future countries. *Frontiers in Environmental Science*, 10(January), 1–18. <https://doi.org/10.3389/fenvs.2022.1076859>
- Westerlund, J.** (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*, 69(6), 709–748. <https://doi.org/10.1111/j.1468-0084.2007.00477.x>
- Wiedmann, T., & Barrett, J.** (2010). A Review of the Ecological Footprint Indicator—Perceptions and Methods. *Sustainability*, 2(6), 1645–1693. <https://doi.org/10.3390/su2061645>
- Wooldridge, J. M.** (2003). *Econometric Analysis of Cross Section and Panel Data*. MIT Press, Cambridge.
- World Bank.** (2020). *World Development Indicators*. Washington, D.C. <https://databank.worldbank.org/source/world-development-indicators>
- World development indicators.** (2024). *World development indicators*, The World Bank. <https://doi.org/DOI>. <https://doi.org/10.57966/6rwy-0b07>
- World Meteorological Organization.** (2022). *State of Climate in Africa highlights water stress and hazards*. <https://public.wmo.int/en/media/press-release/state-of-climate-africa-highlights-water-stress-and-hazards#:~:text=Temperatures%3A> Africa warmed at an, years on record for Africa.
- Xing, T., Jiang, Q., & Ma, X.** (2017). To facilitate or curb? The role of financial development in China's carbon emissions reduction process: A novel approach. *International Journal of Environmental Research and Public Health*, 14(10). <https://doi.org/10.3390/ijerph14101222>
- Xiuzhen, X., Zheng, W., & Umair, M.** (2022). Testing the fluctuations of oil resource price volatility: A hurdle for economic recovery. *SSRN Electronic Journal*, 79, 102982. <https://doi.org/10.2139/ssrn.4123875>
- Xu, Z., Baloch, M. A., Danish, Meng, F., Zhang, J., & Mahmood, Z.** (2018). Nexus between financial development and CO₂ emissions in Saudi Arabia: analyzing the role of globalization. *Environmental Science and Pollution Research*, 25(28), 28378–28390. <https://doi.org/10.1007/s11356-018-2876-3>
- Xue, C., Shahbaz, M., Ahmed, Z., Ahmad, M., & Sinha, A.** (2022). Clean energy consumption, economic growth, and environmental sustainability: What is the role of economic policy uncertainty? *Renewable Energy*, 184, 899–907. <https://doi.org/10.1016/j.renene.2021.12.006>
- Yamego, C. E. W., Omojolaibi, J. A., & Dauda, R. O. S.** (2021). Economic globalisation, institutions and environmental quality in Sub-Saharan Africa. *Research in Globalization*, 3(May 2020), 100035. <https://doi.org/10.1016/j.resglo.2020.100035>
- Yang, C., Liu, L., Yang, W., & Ahmed, T.** (2021). Environmental Regulation, Outward Foreign Direct Investment, and Low-Carbon Innovation: An Empirical Study Based on Provincial Spatial Panel Data in China. *Mathematical Problems in Engineering*, 2021, 1–14. <https://doi.org/10.1155/2021/3021224>

- Yang, L., Bashiru Danwana, S., & Issahaku, F. Y.** (2022). Achieving Environmental Sustainability in Africa: The Role of Renewable Energy Consumption, Natural Resources, and Government Effectiveness—Evidence from Symmetric and Asymmetric ARDL Models. *International Journal of Environmental Research and Public Health*, 19(13), 8038. <https://doi.org/10.3390/ijerph19138038>
- Yang, Y., Lu, H., Liang, D., Chen, Y., Tian, P., Xia, J., Wang, H., & Lei, X.** (2022). Ecological sustainability and its driving factor of urban agglomerations in the Yangtze River Economic Belt based on three-dimensional ecological footprint analysis. *Journal of Cleaner Production*, 330, 129802. <https://doi.org/10.1016/j.jclepro.2021.129802>
- You, W., & Lv, Z.** (2018). Spillover effects of economic globalization on CO₂ emissions: A spatial panel approach. *Energy Economics*, 73, 248–257. <https://doi.org/10.1016/j.eneco.2018.05.016>
- Yousaf, H., Amin, A., Ameer, W., & Akbar, M.** (2022). Investigating the determinants of ecological and carbon footprints. Evidence from high-income countries. *AIMS Energy*, 10(4), 831–843. <https://doi.org/10.3934/energy.2022037>
- Yu, J., Shi, X., Guo, D., & Yang, L.** (2021). Economic policy uncertainty (EPU) and firm carbon emissions: Evidence using a China provincial EPU index. *Energy Economics*, 94, 105071. <https://doi.org/10.1016/j.eneco.2020.105071>
- Yuan, B., & Zhang, Y.** (2020). Flexible environmental policy, technological innovation and sustainable development of China's industry: The moderating effect of environment regulatory enforcement. *Journal of Cleaner Production*, 243, 118543. <https://doi.org/10.1016/j.jclepro.2019.118543>
- Zafar, M. W., Saud, S., & Hou, F.** (2019). The impact of globalization and financial development on environmental quality: Evidence from selected countries in the organization for economic co-operation and development (OECD). *Environmental Science and Pollution Research*, 26(13), 13246–13262. <https://doi.org/10.1007/s11356-019-04761-7>
- Zaghdoudi, T.** (2017). Oil prices , renewable energy , CO₂ emissions and economic growth in OECD countries. *Economics Bulletin*, 37(3), 1844–1850.
- Zahra, S., & Badeeb, R. A.** (2022). The impact of fiscal decentralization, green energy, and economic policy uncertainty on sustainable environment: a new perspective from ecological footprint in five OECD countries. *Environmental Science and Pollution Research*, 29(36), 54698–54717. <https://doi.org/10.1007/s11356-022-19669-y>
- Zaidi, S. A. H., Zafar, M. W., Shahbaz, M., & Hou, F.** (2019). Dynamic linkages between globalization, financial development and carbon emissions: Evidence from Asia Pacific Economic Cooperation countries. *Journal of Cleaner Production*, 228, 533–543. <https://doi.org/10.1016/j.jclepro.2019.04.210>
- Zerrin, K., & Yasemin, D.** (2018). Empirical, The Impact of Globalization on Economic Growth: Turkey, Evidence from the. *International Journal of Economics and Financial*, 8(5), 115-123.

- Zhang, K., & Wang, X.** (2021). Pollution haven hypothesis of global CO₂, so₂, nox—evidence from 43 economies and 56 sectors. *International Journal of Environmental Research and Public Health*, 18(12). <https://doi.org/10.3390/ijerph18126552>
- Zhang, M., Ajide, K. B., & Ridwan, L. I.** (2022). Heterogeneous dynamic impacts of nonrenewable energy, resource rents, technology, human capital, and population on environmental quality in Sub-Saharan African countries. *Environment, Development and Sustainability*, 24(10), 11817–11851. <https://doi.org/10.1007/s10668-021-01927-7>
- Zhang, W., Huang, Y., & Wu, H.** (2022). The symmetric and asymmetric effects of economic policy uncertainty and oil prices on carbon emissions in the USA and China: evidence from the ARDL and non-linear ARDL approaches. *Environmental Science and Pollution Research*, 29(18), 26465–26482. <https://doi.org/10.1007/s11356-021-17839-y>
- Zhang, Y. J.** (2011). The impact of financial development on carbon emissions: An empirical analysis in China. *Energy Policy*, 39(4), 2197–2203. <https://doi.org/10.1016/j.enpol.2011.02.026>
- Zhao, H.** (2022). Research on the Positive Effect of Improving the Quality of FDI on Improving Environmental Pollution. *BCP Business & Management*, 17, 270–278. <https://doi.org/10.54691/bcpbm.v17i.400>
- Zhao, Z., & Peng, C.** (2024). The Dual Impact of FDI on Environmental Quality in Host Countries: A Study on the Heterogeneity of Effects in Developing and Developed Nations. *Journal of Applied Economics and Policy Studies*, 6(1), 85–92. <https://doi.org/10.54254/2977-5701/6/2024052>
- Zhou, X., Dai, M., Ma, X., Charles, V., Shahzad, U., & Zhao, X.** (2024). Economic policy uncertainty and the inhibitory effect of firms' green technology innovation. *Global Finance Journal*, 60, 100960. <https://doi.org/10.1016/j.gfj.2024.100960>
- Zhu, H., Duan, L., Guo, Y., & Yu, K.** (2016). The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: Evidence from panel quantile regression. *Economic Modelling*, 58, 237–248. <https://doi.org/10.1016/j.econmod.2016.05.003>
- Zhu, Y., Bashir, S., & Marie, M.** (2022). Assessing the Relationship between Poverty and Economic Growth: Does Sustainable Development Goal Can be Achieved? *Environmental Science and Pollution Research*, 29(19), 27613–27623. <https://doi.org/10.1007/s11356-021-18240-5>
- Zoundi, Z.** (2017). CO₂ emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renewable and Sustainable Energy Reviews*, 72(October 2016), 1067–1075. <https://doi.org/10.1016/j.rser.2016.10.018>



APPENDIX

APPENDIX A: Chapter 2 Apendices



Table A. 1: List of countries.

Countries	CODE	Countries	CODE
Algeria	DZA	Liberia	LBR
Angola	AGO	Libya	LYB
Benin	BEN	Madagascar	MDG
Botswana	BWA	Malawi	MWI
Burkina Faso	BFA	Mali	MLI
Burundi	BDI	Mauritania	MRT
Cabo Verde	CPV	Mauritius	MUS
Cameroon	CMR	Morocco	MAR
Central African Republic	CAF	Mozambique	MOZ
Chad	TCD	Namibia	NAM
Comoros	COM	Niger	NER
Congo, Dem. Rep.	COD	Nigeria	NGA
Congo, Rep.	COG	Rwanda	RWA
Cote d'Ivoire	CIV	Sao Tome and Principe	STP
Djibouti	DJI	Senegal	SEN
Egypt, Arab Rep.	EGY	Seychelles	SYC
Equatorial Guinea	GNQ	Sierra Leone	SLE
Eritrea	ERI	South Africa	ZAF
Ethiopia	ETH	Sudan	SDN
Gabon	GAB	Swaziland (Eswatini)	SWZ
Gambia	GMB	Tanzania	TZA
Ghana	GHA	Togo	TGO
Guinea	GIN	Tunisia	TUN
Guinea-Bissau	GNB	Uganda	UGA
Kenya	KEN	Zambia	ZMB
Lesotho	LSO	Zimbabwe	ZWE

Table A. 2: The linear and non-linear effects Globalization on carbon emission in Africa: OLS fixed effects.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII	Model VIII	Model IX
lnECO ₂	0.00502 (0.00553)	-0.000780 (0.00434)	-0.000838 (0.00440)	0.00114 (0.00444)	0.00116 (0.00429)	-0.000740 (0.00434)	-0.000869 (0.00441)	0.000610 (0.00428)	0.000864 (0.00429)
ECO	0.000928 (0.00188)	0.00277** (0.00136)	0.00280** (0.00137)	0.00259* (0.00139)	0.00246* (0.00135)	0.00279** (0.00136)	0.00277** (0.00138)	0.00229* (0.00134)	0.00233* (0.00135)
lnPOP	1.633*** (0.0892)	1.521*** (0.127)	1.919*** (0.0925)	1.931*** (0.109)	1.224*** (0.162)	1.539*** (0.126)	1.915*** (0.0937)	1.977*** (0.105)	1.241*** (0.163)
lnENC	0.437*** (0.0795)	0.387*** (0.0704)	0.417*** (0.0705)	0.440*** (0.0714)	0.428*** (0.0690)	0.379*** (0.0708)	0.419*** (0.0710)	0.307*** (0.0725)	0.458*** (0.0736)
lnFD	-0.139*** (0.0477)	-0.0132 (0.0489)	-0.0156 (0.0499)	0.0165 (0.0498)	-0.0150 (0.0485)	-0.0163 (0.0490)	-0.0156 (0.0500)	-0.0288 (0.0486)	-0.00279 (0.0495)
lnGLOB		0.812*** (0.177)							
lnECONGLOB			0.330*** (0.0974)				0.715 (1.374)		
lnPOLGLOB				-0.0106 (0.126)				-6.214*** (1.079)	
lnSOGLOB					0.483*** (0.0925)				1.063** (0.493)

Table A. 2 (continued): The linear and non-linear effects Globalization on carbon emission in Africa: OLS fixed effects.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII	Model VIII	Model IX
lnGLOB2						0.103***			
						(0.0229)			
lnECONGLOB2							-0.0507		
							(0.181)		
lnPOLGLOB2								0.805***	
								(0.139)	
lnSOGLOB2									-0.0880
									(0.0735)
Constant	-20.79***	-21.51***	-26.28***	-25.24***	-15.53***	-20.16***	-26.95***	-13.45***	-16.90***
	(1.484)	(1.662)	(1.504)	(1.550)	(2.348)	(1.835)	(2.831)	(2.528)	(2.612)
Observations	530	464	464	464	464	464	464	464	464
R-squared	0.495	0.699	0.693	0.684	0.703	0.699	0.693	0.708	0.704
Number of ID	37	37	37	37	37	37	37	37	37

Table A. 3: The Linear and nonlinear effect of financial development on carbon emission in Africa: OLS fixed effects results.

Variables	Model I	Model II	Model III	Model IIV	Model V	Model VI	Model VII
lnECO ₂	-0.00251 (0.00439)	-0.00155 (0.00430)	-0.00623 (0.00501)	-0.000314 (0.00428)	-0.000857 (0.00428)	-0.00658 (0.00497)	0.00175 (0.00422)
ECO	0.00160 (0.00134)	0.00298** (0.00135)	0.00324** (0.00144)	0.00307** (0.00134)	0.00290** (0.00134)	0.00322** (0.00143)	0.00315* (0.00132)
lnPOP	1.457*** (0.128)	1.455*** (0.124)	1.516*** (0.137)	1.394*** (0.128)	1.506*** (0.126)	1.490*** (0.136)	1.405*** (0.126)
lnENC	0.450*** (0.0725)	0.390*** (0.0698)	0.339*** (0.0742)	0.396*** (0.0696)	0.401*** (0.0695)	0.293*** (0.0757)	0.445*** (0.0691)
lnGLOB	0.775*** (0.182)	0.689*** (0.180)	0.765*** (0.202)	0.695*** (0.178)	0.669*** (0.179)	0.805*** (0.201)	0.625*** (0.175)
lnFD		0.842*** (0.324)			1.190*** (0.353)		
lnFD2			0.273 (0.234)			0.302 (0.232)	
lnFM				0.805*** (0.266)			1.719*** (0.335)
lnFI					0.0235** (0.00985)		
lnFM2						0.000604** (0.000232)	
lnFI2							0.0568** (0.0131)
Constant	-20.69*** (1.549)	-20.06*** (1.561)	-20.60*** (1.650)	-19.19*** (1.639)	-21.06*** (1.607)	-20.07*** (1.650)	- 19.78*** (1.611)
Observations	478	464	382	464	464	382	464
R-squared	0.670	0.704	0.680	0.706	0.708	0.686	0.718
Number of ID	38	37	31	37	37	31	37

Table A. 4: The Moderate Effect of Globalisation and Financial Development on CO₂ emissions in Africa. OLS fixed effects.

Variables	Model I	Model II	Model III	Model IIV	Model V	Model VI	Model VII
lnECO ₂	-0.000632 (0.0043)	-0.00951* (0.0052)	-0.00129 (0.0043)	-0.000909 (0.0043)	-0.00104 (0.0044)	0.00134 (0.0046)	0.000603 (0.0043)
ECO	-0.00383 (0.00767)	0.0133*** (0.00481)	-0.00440 (0.00565)	0.00278** (0.00136)	0.0145 (0.0367)	0.0199 (0.0233)	0.0252 (0.0162)
lnPOP	1.513*** (0.128)	1.480*** (0.136)	1.516*** (0.128)	1.549*** (0.152)	1.913*** (0.0946)	1.922*** (0.110)	1.214*** (0.162)
lnENC	0.388*** (0.0704)	0.309*** (0.0753)	0.394*** (0.0706)	0.388*** (0.0705)	0.418*** (0.0706)	0.450*** (0.0727)	0.434*** (0.0691)
lnGLOB	0.813*** (0.177)	0.856*** (0.196)	0.809*** (0.177)	0.755*** (0.247)			
lnFD	-0.00690 (0.0494)			-0.0155 (0.0494)	-0.0143 (0.0501)	0.0181 (0.0499)	-0.0119 (0.0485)
lnFDECO	-0.00312 (0.00357)						
lnFM		- 0.0191*** (0.00677)					
lnFMECO		0.00120** (0.00055)					
lnFI			-0.00886 (0.0460)				
lnFIECO			-0.00485 (0.00372)				
lnGLOBECO				0.0445 (0.134)	0.332*** (0.0977)		
lnECONGLO B					-0.00297 (0.0093)		

Table A. 4 (continued): The Moderate Effect of Globalisation and Financial Development on CO₂ emissions in Africa: OLS fixed effects.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
lnECONECO						-0.00100 (0.127)	
lnPOLGLOB						-0.00425 (0.00572)	
lnPOLECO							0.489*** (0.0924)
lnSOGLOB							-0.00600 (0.00426)
Constant	-21.37*** (1.671)	-20.26*** (1.633)	-21.44*** (1.658)	-21.92*** (2.064)	-26.19*** (1.533)	-25.19*** (1.553)	-15.42*** (2.347)
Observations	464	382	464	464	464	464	464
R-squared	0.700	0.689	0.700	0.699	0.693	0.685	0.705
Number of ID	37	31	37	37	37	37	37



CURRICULUM VITAE

Name Surname : Derese Kebde TEKLIE

EDUCATION

- **B.Sc.** : 2009, Mekelle University, Economics
- **M.Sc.** : 2016, Debre Markos University, Development Economic

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2018-2025 Graduate Student in Istanbul Technical University
- 2018 Türkiye Scholarships Awards
- 2016 -2018 Comercial Bank of Ethiopia

PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- **Teklie, D. K., & Yağmur, M. H. (2024).** The Role of Green Innovation, Renewable Energy, and Institutional Quality in Promoting Green Growth: Evidence from African Countries. *Sustainability*, *16*(14), 6166. <https://doi.org/10.3390/su16146166>
- **Teklie, D. K., & Yağmur, M. H. (2024).** Effect of Economic Growth on CO₂ Emission in Africa: Do Financial Development and Globalization Matter?. *International Journal of Energy Economics and Policy*, *14*(1), 121–140. <https://doi.org/10.32479/ijeep.15141>