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**The effect of Industrial Dynamics on Carbon Dioxide Emissions in Africa's
Manufacturing Sector and the Moderating Role of Industrial Emissions Policies**

Gathuru Edmund Kanyugi

048990

**A Research Thesis Submitted to Strathmore Business School in Partial Fulfilment of
the Requirements for the Degree of Master of Science in Development Finance**

VT OMNES VNVM SINT

Strathmore Business School

Strathmore University

Nairobi, Kenya

December 2025

Declaration and Approval

Declaration

I Declare that this research thesis is my original work and has not been presented for a degree or any other award in Strathmore University or to any other institution. To the best of my knowledge the research thesis contains no material previously published except where due reference is made.

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Approval

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Abstract

Africa's manufacturing sector is a critical driver of economic growth but also a significant contributor to Carbon dioxide (CO₂) emissions due to its reliance on energy-intensive processes and outdated technologies. Despite global efforts to promote efficiency and reduce emissions, limited research exists on the effect of industrial dynamics on CO₂ emissions in Africa's manufacturing sector. This study addressed this by investigating the effect of manufacturing sector's share of GDP, energy consumption efficiency and scientific innovations on CO₂ emissions, with a specific focus on the moderating role of industrial emissions policies. The study adopted the Environmental Kuznets Curve (EKC) hypothesis and the Resource Curse theory as its theoretical frameworks. The study targeted manufacturing sectors in forty-seven (47) African countries. Data was sourced from the World Bank, United Nations Industrial Development Organization (UNIDO), and Climate Watch. A panel data regression model was used to analyze the relationship between the variables, with industrial emissions policies measured through industrial emissions intensity. Descriptive statistics revealed wide disparities in emissions and energy use, with concentrations in a few industrial hubs. Correlation analysis showed strong positive links between emissions, manufacturing output and emission intensity, while innovation was associated with higher emissions in the short run. Results from the Random Effects GLS model indicated that energy intensity and manufacturing share of GDP significantly reduce emissions, whereas innovation increases them, highlighting the need to align R&D with low-carbon objectives. Incorporating industrial emission intensity improved model fit, confirming its positive effect on emissions and emphasizing the importance of emission standards, energy efficiency programs and regional collaboration to decouple industrial growth from environmental degradation.

Key Words: Industrial Dynamics, Industrial Emissions Policies, Carbon Dioxide Emissions, Manufacturing Sector, Manufacturing sector's share of GDP, Energy consumption efficiency, Scientific innovations.

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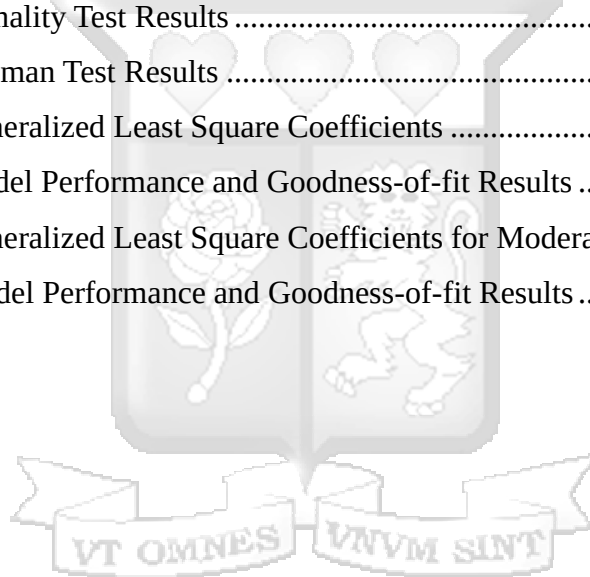
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List of Abbreviations and Acronyms

CO₂: Carbon Dioxide

EKC: Environmental Kuznets Curve

GDP: Gross Domestic Product

GHG: Global Greenhouse Gas

ICTs: Information and Communication Technologies

IEA: International Energy Agency

IE: Industrial Energy Efficiency

OECD: Organization for Economic Cooperation and Development

R&D: Research and Development

ICTs: Information and Communication Technologies

UK: United Kingdom

UNIDO: United Nations Industrial Development Organization

US: United States

WDI: World Development Indicators



Definition of Terms

Industrial dynamics: refers to the complex and evolving interactions among various economic, technological, and production-related forces that shape the structure, performance, and environmental outcomes of the manufacturing sector over time (Alaganthiran & Anaba, 2022).

Industrial Emissions Policies: Policies, programs, and measures implemented to improve energy use efficiency in industrial processes, reduce energy intensity, and lower CO₂ emissions in the manufacturing sector. These include energy management systems, adoption of ISO 50001 standards, and incentives for integrating energy-efficient technologies (Salari et al., 2021).

CO₂ Emissions: The release of carbon dioxide into the atmosphere resulting from industrial processes, energy consumption efficiency, and manufacturing activities. In this study, it is measured in metric tons and focuses on emissions specific to the manufacturing sector (Yazdi & Dariani, 2019).

Manufacturing Sector: The segment of the economy involved in the production and processing of goods using machinery, labor, and energy. It includes industries such as mining, cement production, oil refining, and metal processing (Yazdi & Dariani, 2019).

Economic Growth: The increase in a country's output of goods and services over time, measured through GDP (Gross Domestic Product) (Mikayilov et al., 2018).

Energy consumption efficiency: The amount of energy used by the manufacturing sector for production processes. It is measured through energy intensity, defined as energy consumption efficiency per unit of industrial output (Alaganthiran & Anaba, 2022).

Scientific innovations: The development, adoption and implementation of new technologies and processes that improve energy efficiency and reduce environmental impact in the manufacturing sector. It is measured through indicators, such as R&D

investments, scientific journal publications, green patents and adoption of renewable energy technologies (Salari et al., 2021).



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Dedication

I dedicate this work to my father, Josphat John Gathuru Kanyugi.



Chapter 1: Introduction

1.1 Background of the Study

Carbon dioxide (CO₂) emissions are a critical global concern due to their direct link to climate change, environmental degradation and public health threats. Globally, CO₂ accounts for about 75% of greenhouse gas emissions, primarily driven by industrial activities, fossil fuel use and energy consumption efficiency (Popkova & Sergi, 2021). In Africa, the manufacturing sector, while a key contributor to economic growth, is also a significant source of CO₂ emissions due to its dependence on carbon-intensive energy sources and inefficient technologies (Alaganthiran & Anaba, 2022). As industrialization accelerates across the continent, CO₂ emissions are expected to rise sharply unless deliberate mitigation strategies are implemented. According to Amri et al. (2019) industrial emissions in some African economies such as South Africa and Nigeria are among the highest on the continent, underscoring the urgent need for sustainable industrial development pathways (Alaganthiran & Anaba, 2022). Addressing CO₂ emissions from the manufacturing sector is not only essential for meeting international climate targets but also for securing long-term socio-economic and environmental resilience in Africa.

One of the most promising approaches to understanding rising emissions lies in examining the effect of industrial dynamics on carbon dioxide emissions in Africa's manufacturing sector. Industrial dynamics; including manufacturing sector's share of GDP, energy consumption efficiency behaviors and scientific innovations are key drivers that are likely to influence the level and intensity of emissions (McKane & Price, 2007). Rapid economic growth often leads to expanded manufacturing activities, increasing fossil fuel consumption and carbon output. Similarly, the surge in commodity production intensifies industrial energy demands, particularly in resource-rich countries, while outdated energy consumption efficiency patterns reinforce dependence on non-renewable energy sources. Scientific innovations, although offering potential for reducing emissions, remains underutilized across much of Africa due to financial, infrastructural, and institutional barriers (Shahbaz, Sharma, Sinha, & Jiao, 2021). Understanding how these industrial dynamics interact provides critical insights into why Africa's CO₂

emissions trajectory continues to rise amid industrialization. Although some interventions, such as global agreements like the Kyoto Protocol, have encouraged cleaner production practices, the pace of change remains slow (McKane & Price, 2007). Against this backdrop, this study will not only analyze the effects of industrial dynamics on CO₂ emissions but will also investigate the role of industrial emissions (IE) policies as a potential moderating factor influencing the relationship between industrial dynamics and carbon dioxide emissions.

1.1.1 Global Perspective on Industrial Dynamics and Carbon Dioxide Emissions

According to Yazdi and Dariani (2019) the manufacturing sector contributes significantly to global CO₂ emissions. This is driven by evolving industrial dynamics; that is economic growth, energy consumption efficiency behaviors and scientific innovations. These dynamics are shaped by the need for industrial expansion and competitiveness, but they also carry substantial environmental costs (Adedoyin & Zakari, 2017). Economic expansion, in particular, has been linked to increased energy use and emissions in both developed and developing economies (Mikayilov et al., 2018). Nations like Azerbaijan and China continue to struggle with rising emissions due to heightened industrial activity, even in the presence of global mitigation frameworks such as the Kyoto Protocol and the Paris Agreement (Yazdi & Dariani, 2019). These challenges highlight the critical role of targeted interventions that account for the unique interplay between industrial dynamics and environmental outcomes.

While the Environmental Kuznets Curve (EKC) hypothesis posits that CO₂ emissions initially rise with economic development but eventually decline as economies mature, this trend remains inconsistent, especially in emerging economies. For instance, rapid industrialization in India and Malaysia has resulted in elevated emissions and energy demand, contrary to EKC predictions (Adedoyin & Zakari, 2017; Mikayilov et al., 2018). This inconsistency points to a global research gap in understanding how the structure of economic growth and industrial composition affect emissions. Such gaps necessitate deeper exploration into how technological capabilities, policy frameworks, and industrial practices either amplify or mitigate the environmental impacts of industrial growth.

Energy consumption efficiency, particularly from non-renewable sources, further compounds the emissions problem. Studies in countries such as the U.S. and U.K. reveal a direct correlation between fossil fuel use and rising CO₂ emissions, whereas increased renewable energy adoption tends to reverse this trend (Salari et al., 2021; Adedoyin & Zakari, 2017). However, many Asian economies continue to depend heavily on fossil fuels, making emission reductions more difficult (Yazdi & Dariani, 2019). Similarly, scientific innovations, which holds promise for cleaner industrial processes and energy efficiency, remains unevenly distributed. In many developing countries, financial and infrastructural limitations inhibit the widespread adoption of energy-saving technologies (Mikayilov et al., 2018), creating a further divide in emissions outcomes between advanced and emerging economies.

Amid these complexities, industrial emissions (IE) policies emerge as a crucial moderating variable that can alter the relationship between industrial dynamics and CO₂ emissions. These policies, which include energy audits, ISO 50001 adoption and clean technology incentives, have proven effective in countries with supportive institutional frameworks. For example, U.K. has reduced emissions through cleaner energy and innovation (Adedoyin & Zakari, 2017; Salari et al., 2021). In summary, global evidence demonstrates that industrial dynamics are key drivers to CO₂ emissions, but their impacts can be moderated by robust IE policies.

1.1.2 Africa Perspective on Industrial Dynamics and Carbon Dioxide Emissions

In Africa, CO₂ emissions from the manufacturing sector present a growing environmental concern, particularly as industrialization gains momentum across the continent. The manufacturing sector, while vital for employment, GDP growth and regional development, remains highly energy-intensive, heavily reliant on fossil fuels, and burdened by outdated technologies (Kwakwa et al., 2018; Aye & Edoja, 2017). Countries such as Nigeria, Ghana, and Kenya have recorded significant increases in emissions as a direct result of industrial expansion and increased demand for commodity production, yet their adoption of clean energy practices remains minimal (Alaganthiran & Anaba, 2022). The continued growth of CO₂ emissions in the sector highlights the need for well-structured interventions that address the environmental impact of industrial activities.

This study focuses on industrial dynamics; specifically manufacturing sector share of GDP, energy consumption efficiency behaviors and scientific innovations as the key independent variables that influence CO₂ emissions in Africa's manufacturing sector. Economic expansion in countries like Ghana and Kenya has been accompanied by increased industrial output and urbanization, which in turn drive up energy demand and emissions (Kwakwa et al., 2018; Alaganthiran & Anaba, 2022). Similarly, the high dependence on commodity extraction in nations such as Nigeria and Angola have intensified emissions due to the energy demands of mining and resource processing (Aye & Edoja, 2017). These patterns emphasize the urgent need for economic and production strategies that incorporate sustainability principles.

Scientific innovations, though promising, is underutilized across the continent. Countries such as Tunisia have begun integrating ICTs and other innovations into manufacturing processes, which have improved productivity but achieved limited impact on emissions without broader supporting policies (Amri et al., 2019). Moreover, limited R&D investment, insufficient technology transfer, and inadequate infrastructure continue to hinder the scaling of cleaner industrial technologies across Sub-Saharan Africa (Aye & Edoja, 2017). This demonstrates the importance of not only promoting innovation but also embedding it within a robust policy and institutional framework. In this context, industrial energy efficiency (IE) policies function as a crucial moderating variable in the relationship between industrial dynamics and CO₂ emissions. These policies; ranging from energy audits and ISO 50001 certification to subsidies for energy-efficient technologies are intended to reduce energy intensity and promote cleaner industrial practices (Amri et al., 2019).

However, their adoption and enforcement vary widely across Africa. While South Africa has made commendable progress in implementing renewable energy strategies and industrial energy management, many Sub-Saharan African countries continue to lag behind due to weak institutional capacity and insufficient policy incentives (Amri et al., 2019; Alaganthiran & Anaba, 2022). This inconsistency hampers the effectiveness of IE policies in mitigating emissions, particularly in economies undergoing rapid industrial expansion.

Empirical studies reveal significant research gaps. While literature acknowledges the relationship between economic growth and emissions, there is limited integrated analysis examining how industrial dynamics collectively influence emissions within the moderating context of IE policies. Furthermore, the interaction between scientific innovations and energy consumption efficiency remains understudied in Africa's context, particularly in light of persistent emissions from manufacturing industries (Kwakwa et al., 2018; Amri et al., 2019). These gaps underscore the necessity of empirical investigations that can inform tailored policy responses. This study contributes by assessing how industrial dynamics shape CO₂ emissions and evaluating the extent to which IE policies moderate this relationship in Africa's manufacturing sector.

1.1.3 Industrial Emissions Policies

According to Popkova and Sergi (2021) Industrial Emissions policies (IE) have emerged as a crucial strategy for mitigating carbon dioxide (CO₂) emissions, particularly from the manufacturing sector, which remains one of the most energy-intensive and polluting industries worldwide. The global momentum for IE policies was catalyzed by the Kyoto Protocol of 1997, which committed industrialized nations and encouraged developing countries to adopt measures aimed at reducing greenhouse gas emissions (McKane & Price, 2007). This shift recognized that improving energy efficiency, particularly within industries, could deliver significant and cost-effective emission reductions without compromising economic growth. According to the International Energy Agency (IEA), improving industrial energy efficiency alone could contribute up to 26% of the total global emission reductions needed by 2050 to meet climate targets (Popkova & Sergi, 2021).

In Africa, the adoption of IE policies gained momentum in the early 2000s, as countries sought to align with international environmental agreements while pursuing industrialization (Amri et al., 2019). However, progress has been uneven, hampered by weak institutional frameworks, limited technical capacity and inadequate financing mechanisms (Alaganthiran & Anaba, 2022). Industrial energy efficiency measures such as energy audits, ISO 50001 certifications, performance-based standards and incentives

for cleaner technologies have been introduced but remain inconsistently applied across the continent (McKane & Price, 2007).

The moderating role of IE policies is particularly critical in Africa's context, where industrial dynamics; manufacturing sector share of GDP, energy consumption efficiency and scientific innovations are intensifying CO₂ emissions. Robust IE policies can weaken the positive relationship between industrial dynamics and emissions by promoting cleaner production, optimizing energy use and incentivizing technological upgrading (Amri et al., 2019; Shahbaz, Sharma, Sinha, & Jiao, 2021). Despite this potential, few studies have empirically assessed how IE policies moderate the effects of industrial dynamics on emissions in Africa's manufacturing sector. Given Africa's rapid industrialization and vulnerability to climate change, there is an urgent need for targeted research to bridge this knowledge gap and inform sustainable industrial policies.

1.2 Statement of the Problem

The manufacturing sector remains central to Africa's economic transformation, contributing approximately 10% to Africa's GDP and employing millions across the continent (Kwakwa et al., 2018). However, it is also a major contributor to rising CO₂ emissions, accounting for nearly 30% of Africa's industrial greenhouse gas emissions due to its dependence on fossil fuels, outdated technologies and inefficient production processes (Popkova & Sergi, 2021). While industrial emissions (IE) policies have been effective in reducing emissions by up to 20–30% in developed economies, their implementation and impact across Africa remain fragmented and limited (Mikayilov et al., 2018; Amri et al., 2019).

Empirical evidence shows that economic growth in countries like Kenya, Nigeria and Ghana has been strongly associated with increased CO₂ emissions, largely due to the energy demands of expanded manufacturing activities (Alaganthiran & Anaba, 2022; Kwakwa et al., 2018). Similarly, commodity production in resource-rich economies such as Nigeria and Angola drive emissions higher through energy-intensive extraction and processing (Aye & Edoja, 2017). Despite global trends toward renewable energy, non-renewable energy sources still account for over 75% of energy consumption efficiency in

Africa's manufacturing sector (Adedoyin & Zakari, 2020). Although scientific innovations could significantly reduce emissions, it remains underutilized due to low R&D investment which is less than 0.5% of GDP in most African countries (Amri et al., 2019).

There is a conceptual gap in existing studies, as no research that has examined the moderating role of IE policies on the relationship between industrial dynamics and carbon dioxide emissions in Africa's manufacturing sector. Additionally, a contextual gap persists, with most studies limited to individual countries rather than covering all 54 African nations. This study addressed both gaps by comprehensively investigating how industrial dynamics influence CO₂ emissions across Africa's manufacturing sector, and how IE policies shaped this relationship to foster sustainable industrial development.

1.3 Research Objectives

The study was guided by the following research objectives:

1.3.1 General Research Objective

The general objective of the study was to investigate the effect of industrial dynamics on carbon dioxide emissions in Africa's manufacturing sector.

1.3.2 Specific Research Objectives

- i. To examine the effect of the manufacturing sector's share of GDP on carbon dioxide emissions in Africa's manufacturing sector.
- ii. To examine the influence of energy consumption efficiency on carbon dioxide emissions in Africa's manufacturing sector.
- iii. To establish the effect of scientific innovations on carbon dioxide emissions in Africa's manufacturing sector.
- iv. To examine the moderating role of industrial emissions policies between industrial dynamics and carbon dioxide emissions in Africa's manufacturing sector.

1.4 Research Questions

The study was guided by the following research questions:

- i. What is the effect of the manufacturing sector's share of GDP on carbon dioxide emissions in Africa's manufacturing sector?
- ii. What is the influence of energy consumption efficiency on carbon dioxide emissions in Africa's manufacturing sector?
- iii. What is the effect of scientific innovations on carbon dioxide emissions in Africa's manufacturing sector?
- iv. What is the moderating role of industrial emissions policies between industrial dynamics and carbon dioxide emissions in Africa's manufacturing sector?

1.5 Significance of the Study

1.5.1 Policymakers and Government Agencies

This study offers critical insights for policymakers and government agencies across Africa by empirically analyzing the relationship between industrial dynamics and CO₂ emissions, with industrial emissions (IE) policies as a moderating factor. By evaluating how manufacturing sector share of GDP, energy consumption efficiency, and scientific innovations influence emissions, the study provides a robust evidence base to inform the formulation of targeted industrial and environmental policies. The findings support the design and implementation of integrated strategies that promote industrial development while minimizing environmental degradation, aligning national economic goals with global climate commitments such as the Paris Agreement. The study also proposes a framework for incorporating renewable energy sources and energy-efficient technologies into national industrial policies, thereby fostering sustainable development.

1.5.2 Manufacturers, Business Leaders and Investors

For industrial stakeholders, including manufacturers, business leaders, and investors, the study underscores the economic and environmental benefits of adopting energy-efficient technologies and sustainable production practices. By highlighting the link between improved energy efficiency and reduced CO₂ emissions, the findings encourage industry players to invest in innovation and cleaner technologies. This not only enhances operational efficiency and cost savings but also facilitates compliance with international environmental standards and market expectations. The study thus serves as a strategic resource for guiding investment decisions and corporate sustainability planning.

1.5.3 Environmental Advocacy Groups and Researchers

The study is of high relevance to environmental advocacy groups and academic researchers, providing updated empirical data and analytical frameworks on emissions trends within Africa's manufacturing sector. It enables stakeholders in environmental governance and academia to better understand the structural and policy-related drivers of emissions. This information is instrumental in designing advocacy campaigns, shaping public discourse, and identifying new areas for environmental and economic research focused on low-carbon industrial development.

1.5.4 International Organizations and Development Partners

For international development agencies and climate-focused organizations, the study delivers actionable insights on the state of energy use and emissions in Africa's manufacturing sector. It identifies policy and technological gaps that require international funding, capacity building, and technical support. The study's findings can inform program development, donor funding priorities, and international cooperation frameworks aimed at achieving climate-resilient and inclusive industrialization across the continent.

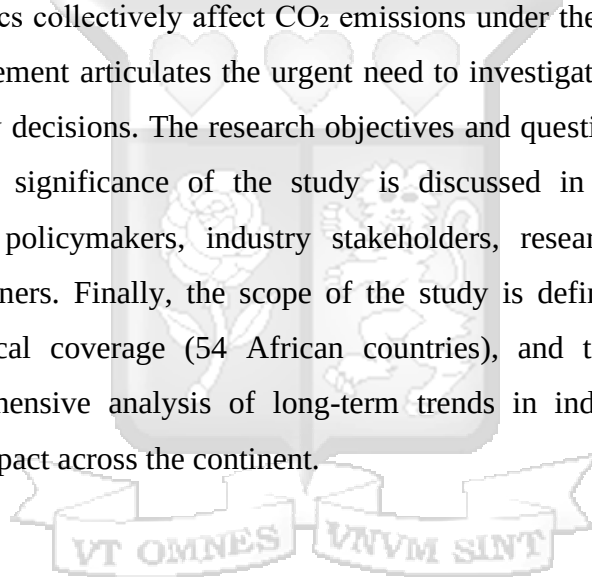
1.6 Scope of the Study

The study focused on analyzing the effects of industrial dynamics on CO₂ emissions in Africa's manufacturing sector. It examines the interplay between manufacturing sector's share of GDP, energy consumption efficiency and scientific innovations adoption in influencing emissions. The geographical scope included forty-seven (47) African countries whose data was readily available. The study evaluated data spanning from 2000 to 2022 to capture evolving trends in policy implementation, industrial development, and environmental impact. By addressing these dimensions, the study provides a comprehensive understanding of the manufacturing sector's environmental challenges and opportunities for sustainable growth within the African context.

1.7 Chapter Summary

Chapter One introduces the study by highlighting the growing concern over CO₂ emissions in Africa's manufacturing sector, which is both a driver of economic growth

and a major contributor to environmental degradation. The chapter introduces CO₂ emissions as the dependent variable, contextualizing their global and regional significance, especially in the wake of industrialization, fossil fuel dependence, and outdated production technologies. It then presents industrial dynamics; comprising manufacturing sector share of GDP, energy consumption efficiency and scientific innovations as the independent variables influencing emissions. The chapter emphasizes the critical role of Industrial Emissions (IE) policies as a moderating variable, which could weaken or alter the strength of the relationship between industrial dynamics and emissions. Drawing from global and African empirical literature, the chapter identifies key research gaps, particularly the lack of integrated analysis exploring how these industrial dynamics collectively affect CO₂ emissions under the influence of IE policies. The problem statement articulates the urgent need to investigate this interplay to inform sustainable policy decisions. The research objectives and questions are outlined to guide the inquiry. The significance of the study is discussed in relation to its practical contributions to policymakers, industry stakeholders, researchers, and international development partners. Finally, the scope of the study is defined in terms of thematic focus, geographical coverage (54 African countries), and time range (2000–2024), ensuring comprehensive analysis of long-term trends in industrial development and environmental impact across the continent.



Chapter 2: Literature Review

2.1 Introduction

This chapter presents a review of the relevant literature. The chapter covers: theoretical background, empirical review, summary of research gaps, conceptual framework, operationalization of variables and a summary of the chapter.

2.2 Theoretical Background

To ground this study theoretically, two key frameworks were selected based on their relevance to the relationship between industrial dynamics and CO₂ emissions in Africa's manufacturing sector: the Environmental Kuznets Curve (EKC) Hypothesis and the Resource Curse Theory. The EKC hypothesis provides insights into how economic growth and energy consumption efficiency initially increase environmental degradation but may later lead to emission reductions through technological advancement and policy interventions. This aligns with the study's focus on the effects of economic growth and energy consumption efficiency. The Resource Curse Theory, on the other hand, explains how heavy reliance on natural resource-based commodity production and weak institutional governance can exacerbate emissions, making it particularly relevant to the study's examination of scientific innovations. Together, these theories support the investigation of how industrial dynamics contribute to emissions and how Industrial Emissions (IE) policies may moderate these effects in Africa's rapidly industrializing economies.

2.2.1 Environmental Kuznets Curve (EKC) Hypothesis

The Environmental Kuznets Curve (EKC) hypothesis, originally introduced by Simon Kuznets (1955) to describe the relationship between economic growth and income inequality, was extended to environmental studies in the 1990s by Grossman and Krueger (1991). The EKC proposes an inverted U-shaped relationship between economic growth and environmental degradation. At the early stages of economic growth, industrialization and urbanization lead to increased exploitation of natural resources and reliance on fossil fuels, resulting in heightened environmental degradation. However, as economies grow and achieve higher income levels, a shift occurs where investments in clean technologies,

stricter environmental regulations, and societal demand for sustainable practices begin to mitigate environmental harm (Grossman & Krueger, 1995; Acheampong, 2018).

The EKC has undergone significant refinements, incorporating additional variables such as trade openness, energy efficiency, and scientific innovations (Amri et al., 2019; Du et al., 2019). In the context of CO₂ emissions, it posits that as countries transition to advanced stages of development, they achieve a decoupling of economic growth from environmental degradation. For example, countries like South Africa, which are further along the industrialization pathway compared to other African nations, have started integrating renewable energy into their manufacturing processes, aligning with the EKC framework (Kwakwa et al., 2018; Dauda et al., 2021).

Despite its widespread use, the EKC hypothesis has faced substantial critiques. Critics argue that the theory oversimplifies the growth-environment relationship by assuming all nations will follow a similar trajectory, neglecting differences in institutional capacity, resource endowments, and economic structures (Mensah et al., 2019; Mikayilov et al., 2018). Furthermore, the EKC does not account for the possibility of irreversible environmental damage during the early stages of economic growth or global spillover effects from localized emissions. For instance, many African countries face unique challenges such as weak enforcement of environmental regulations and dependence on resource extraction, making it difficult to achieve the downward slope of the EKC curve. The EKC hypothesis is particularly relevant to the study's objectives of assessing the effect of manufacturing sector's share of GDP and energy consumption efficiency on CO₂ emissions in Africa's manufacturing sector. It provides a framework to evaluate whether the continent's manufacturing activities are moving toward or away from sustainable industrial practices. By analyzing Africa's position on the EKC trajectory, the study identified critical policy and technological interventions needed to accelerate the transition to low-carbon industrialization.

2.2.2 Resource Curse Theory

The Resource Curse Theory, popularized by Richard Auty in 1993, explains the paradox wherein countries rich in natural resources often experience slower economic growth,

poor governance, and environmental degradation compared to resource-scarce nations. Sachs and Warner (1995) expanded this theory, identifying the mechanisms through which resource wealth can hinder development, such as economic volatility, rent-seeking behavior, and underinvestment in critical sectors like education, infrastructure and technology. Over time, researchers have linked the resource curse to environmental degradation, arguing that resource-rich countries often rely on energy-intensive industries that contribute significantly to CO₂ emissions (Aye & Edoja, 2017; Tost et al., 2018).

One key development of the Resource Curse Theory is its focus on the role of institutional quality in moderating the relationship between resource wealth and developmental outcomes. Strong institutions and governance are essential to ensuring that resource wealth is used to fund sustainable practices rather than perpetuating inefficiencies and environmental harm (Shahbaz et al., 2018). For example, while countries like Zambia and Nigeria face significant environmental challenges due to their reliance on mining and oil extraction, South Africa's relatively stronger institutional framework has allowed for incremental progress in adopting cleaner technologies (Shahzad et al., 2020; Wenlong et al., 2023).

Despite its contributions, the Resource Curse Theory has been critiqued for its deterministic approach, which overlooks countries that have successfully managed their resources through effective policies. Critics also argue that the theory underestimates the role of global market dynamics, such as trade globalization, in shaping resource dependence and emissions outcomes (Dauda et al., 2021; Khan et al., 2020). Additionally, the theory's traditional focus on economic outcomes has led to limited exploration of its environmental implications, particularly in developing regions like Africa.

The Resource Curse Theory is relevant to the study's focus on the effects of scientific innovations on CO₂ emissions in Africa's manufacturing sector. It provides insights into how reliance on resource-intensive industries contributes to emissions and highlights the critical need for institutional reforms and investments in clean technologies. By addressing the barriers to innovation and sustainability in Africa's resource-dependent

manufacturing sector, the study aimed to fill gaps in understanding the resource-environment nexus.

2.3 Empirical Review

The section covers the empirical review.

2.3.1 Effect of Manufacturing Sector's Share of GDP on CO₂ Emissions in Africa's Manufacturing Sector

Economic growth is often cited as a key driver of CO₂ emissions due to the increased industrial activities and energy consumption efficiency that accompany it. In Africa, the relationship between economic growth and emissions has been complex and context-dependent. Studies highlight that economic growth in resource-rich countries such as Nigeria and Angola are closely tied to the expansion of energy-intensive industries, leading to heightened CO₂ emissions (Aye & Edoja, 2017; Kwakwa et al., 2018). This is particularly evident in regions where industrialization relies heavily on fossil fuels and where energy-efficient technologies are scarce, raising concerns about sustainable growth trajectories in Africa.

The Environmental Kuznets Curve (EKC) hypothesis, which posits that emissions rise with economic growth before declining at higher income levels, has been tested in African contexts with mixed results. Evidence from Ghana and South Africa suggests that economic growth initially exacerbates emissions due to increased manufacturing output and urbanization (Acheampong, 2018; Kwakwa et al., 2018). However, these economies have not consistently reached the income levels necessary to observe a decline in emissions, unlike some developed nations (Aye & Edoja, 2017). This underscores the need for structural changes in industrial policies to achieve both economic and environmental goals.

Energy consumption efficiency patterns significantly influence the relationship between economic growth and emissions. Research indicates that as African economies grow, their reliance on non-renewable energy sources increases, further amplifying CO₂ emissions (Acheampong, 2018; Mikayilov et al., 2018). For example, Tunisia and Kenya

have experienced rising emissions alongside economic growth, primarily due to the energy demands of expanding industrial activities (Amri et al., 2019). This trend highlights the critical need for integrating renewable energy and energy-efficient technologies into Africa's industrialization strategies. Furthermore, the structure of economic growth in Africa is dominated by resource extraction and commodity-based industries which has unique implications for emissions. Resource-dependent economies such as Nigeria and Zambia often face heightened emissions due to the energy-intensive nature of their industries (Kwakwa et al., 2018; Aye & Edoja, 2017). This is compounded by a lack of diversification and limited adoption of low-carbon technologies, making these economies particularly vulnerable to global climate policies aimed at curbing emissions.

Despite these challenges, scientific innovations offer a potential pathway to decoupling economic growth from emissions. Countries such as South Africa have made strides in renewable energy integration, though these efforts remain insufficient to offset emissions from industrial growth (Acheampong, 2018; Amri et al., 2019). The limited access to financing and technological expertise across much of Africa underscores the importance of international cooperation and investment in energy efficiency and clean technologies. Addressing these gaps is crucial to enabling sustainable growth in Africa's manufacturing sector. This review illustrates the urgent need for targeted research and policy interventions to manage the environmental impacts of economic growth in Africa, aligning with global sustainability objectives while promoting industrial development.

Commodity production is a vital economic driver in Africa, underpinning the growth of manufacturing industries. However, its energy-intensive nature makes it a significant contributor to CO₂ emissions. Studies reveal that the extraction and processing of resources like gold in Ghana, oil in Nigeria, and copper in Zambia are major sources of emissions, primarily due to the reliance on fossil fuels and outdated technologies (Kwakwa et al., 2018; Aye & Edoja, 2017; Mikayilov et al., 2018). The environmental burden of these industries is further exacerbated by weak regulatory frameworks, leading to inefficiencies and high emissions rates. Understanding the emissions impact of

Africa's resource-driven industries is critical for developing sustainable manufacturing practices.

The Environmental Kuznets Curve (EKC) hypothesis, which posits that emissions initially rise with economic growth and later decline at higher income levels, has limited applicability in Africa. Research in Ghana and South Africa shows that commodity-dependent economies often remain at the emissions-intensive stage of development without transitioning to cleaner industrial practices (Amri et al., 2019; Acheampong, 2018). This stagnation is largely attributed to limited technological adoption and weak policy enforcement. While these economies contribute significantly to global commodity markets, their dependence on extractive industries underscores a critical research gap in exploring the interplay between commodity production and emissions in Africa's manufacturing sector.

Global demand for African commodities exacerbates local emissions. For instance, increased oil and gas production in Nigeria and Angola has intensified energy use and CO₂ emissions (Kwakwa et al., 2018; Mikayilov et al., 2018). Similarly, the mining of metals such as gold and copper has been linked to land degradation and significant greenhouse gas emissions (Tost et al., 2018; Shahzad et al., 2020). These trends highlight the role of international market forces in shaping local environmental impacts, necessitating studies that integrate global trade dynamics with emissions outcomes in Africa. Moreover, the inefficiencies in resource-based industries compound emissions challenges. For example, outdated mining practices in Zambia and inadequate energy recovery in Ghana's oil sector contribute to higher emissions intensities compared to global benchmarks (Aye & Edoja, 2017; Amri et al., 2019). The lack of investments in energy-efficient technologies and sustainable processing methods represents a major bottleneck. Research targeting these inefficiencies is essential to identify pathways for reducing emissions while maintaining economic viability in Africa's manufacturing sector.

Despite these challenges, opportunities exist for integrating low-carbon technologies into Africa's commodity production processes. Countries like South Africa have made

progress in renewable energy integration within mining operations, though these efforts remain fragmented (Acheampong, 2018; Shahzad et al., 2020). Bridging the gap between policy intentions and implementation is critical for achieving sustainable industrial growth. This study aims to fill the gaps by examining the specific links between commodity production and emissions in Africa, providing insights for effective policymaking and environmental management. The review demonstrates the urgent need for targeted research to address emissions challenges in Africa's commodity-dependent manufacturing sector. By exploring the interplay between commodity production and policy frameworks, this study seeks to contribute to a more sustainable industrial future for the continent.

2.3.2 Effect of Energy Consumption Efficiency on CO₂ Emissions in Africa's Manufacturing Sector

Energy consumption efficiency patterns in Africa's manufacturing sector are a critical driver of CO₂ emissions, with a direct link to the continent's reliance on fossil fuels for industrial processes. The energy demand in manufacturing is primarily met through non-renewable sources, which intensifies environmental challenges (Acheampong, 2018; Mikayilov et al., 2018). For instance, countries such as South Africa and Nigeria exhibit significant reliance on coal and natural gas, contributing substantially to their emissions profiles (Amri et al., 2019; Tost et al., 2018). The high dependency on traditional energy systems underscores the need for transitioning toward renewable energy sources and improving energy efficiency to mitigate emissions.

The Environmental Kuznets Curve (EKC) hypothesis, which suggests that CO₂ emissions initially rise with economic growth before declining as income levels increase, has been inconsistently observed in African contexts. While some evidence supports the EKC in industrialized nations, African economies often remain in the emissions-intensive phase due to inadequate energy infrastructure and limited access to cleaner energy alternatives (Acheampong, 2018; Adedoyin & Zakari, 2017). For example, in Ghana and Kenya, industrial expansion has led to an increase in emissions without significant progress in adopting low-carbon technologies (Mikayilov et al., 2018; Amri et al., 2019). This

indicates a pressing need to explore energy consumption efficiency and their implications for emissions reduction in Africa.

Energy intensity in manufacturing remains a significant issue across the continent, with outdated technologies and inefficient processes exacerbating emissions. In Tunisia, the integration of renewable energy into industrial operations has shown promise but remains insufficient to address the broader energy challenges (Amri et al., 2019). Similarly, Nigeria's manufacturing sector faces hurdles in adopting energy-efficient technologies due to financial and infrastructural constraints (Acheampong, 2018; Mikayilov et al., 2018). The lack of a robust framework for monitoring and improving energy efficiency represents a critical research gap, calling for targeted studies to develop actionable strategies for sustainable energy use in manufacturing.

Global energy trends also influence Africa's energy consumption efficiency patterns. The growing demand for exports and industrial goods places additional pressure on energy systems, increasing emissions (Kahia et al., 2019; Tost et al., 2018). This is particularly evident in South Africa, where manufacturing output linked to global supply chains drives higher energy consumption efficiency and associated emissions. The reliance on fossil fuels for industrial processes limits the continent's ability to decouple economic growth from environmental degradation, underscoring the need for policies that integrate global best practices with local energy needs.

Addressing these energy challenges requires a multi-faceted approach involving policy interventions, scientific innovations, and investment in renewable energy. Research gaps exist in understanding the regional disparities in energy consumption efficiency and their impact on emissions, as well as in identifying scalable solutions tailored to Africa's unique industrial landscape. This study aims to fill these gaps by examining the relationship between energy consumption efficiency and CO₂ emissions in Africa's manufacturing sector, providing critical insights for achieving sustainable industrial growth. The review highlights the interconnections between energy consumption efficiency and CO₂ emissions, emphasizing the urgency of adopting cleaner energy strategies to foster sustainable development in Africa's manufacturing sector.

2.3.3 Effect of Scientific innovations on CO₂ Emissions in Africa's Manufacturing Sector

Scientific innovations are widely regarded as a crucial factor in reducing CO₂ emissions through improved energy efficiency and cleaner production processes. In Africa's manufacturing sector, however, the adoption of advanced technologies has been slow due to financial and infrastructural constraints. Studies indicate that innovations such as renewable energy technologies, smart manufacturing systems, and low-carbon processes are essential for transitioning to sustainable industrial practices (Dauda et al., 2020; Usman & Hammar, 2021). Countries like South Africa and Egypt have demonstrated some progress in integrating scientific innovations into manufacturing, yet the impact remains limited to certain industries and regions, underscoring a critical gap in widespread adoption across the continent.

Empirical evidence supports the Environmental Kuznets Curve (EKC) hypothesis, suggesting that technological advancements can help reduce emissions once economies reach a certain development stage. In Africa, however, the benefits of innovation often remain unrealized due to low levels of research and development (R&D) investment and the absence of robust policy frameworks (Mensah et al., 2020; Lin & Zhu, 2019). For instance, Tunisia has shown potential in leveraging ICT for energy efficiency, but such initiatives have not been sufficiently scaled across the region (Amri et al., 2019). This indicates a significant research gap in understanding how scientific innovations can be tailored to meet the unique challenges of Africa's manufacturing sector.

Globally, green technology innovations have been shown to mitigate CO₂ emissions, particularly in high-income economies where R&D spending and supportive policies are more prevalent. Studies from outside Africa highlight the importance of patent activity and innovation subsidies in promoting low-carbon technologies (Du et al., 2019; Khan et al., 2023). In contrast, Africa faces challenges such as high upfront costs and limited diffusion of innovations, which hinder the region's ability to replicate these successes. Addressing this disparity requires an in-depth exploration of how local and international collaboration can foster technological progress in Africa's manufacturing sector. Scientific innovations in Africa is further constrained by inadequate access to

international funding and limited collaboration between public and private sectors. Research shows that public-private partnerships (PPPs) can play a pivotal role in overcoming financial barriers and accelerating the adoption of clean technologies (Shahbaz et al., 2019; Ahmed & Le, 2020). However, the implementation of PPPs in Africa remains fragmented, with few initiatives achieving significant results in reducing emissions. This highlights the need for policies that encourage private sector participation and investment in sustainable manufacturing technologies.

Despite these challenges, the potential for scientific innovations to transform Africa's manufacturing sector remains significant. Studies emphasize the importance of integrating green technologies into industrial processes and fostering regional cooperation to scale successful initiatives (Wenlong et al., 2022; Khan et al., 2023). This study aims to fill the research gaps by investigating the specific role of scientific innovations in reducing CO₂ emissions in Africa's manufacturing sector, providing actionable insights to guide policymakers, investors, and industry stakeholders toward a low-carbon future. This underscores the critical role of scientific innovations in mitigating CO₂ emissions and highlights the urgent need for targeted research and investment to unlock its full potential in Africa's manufacturing sector.

2.3.4 The Moderating Role of Industrial Emissions Policies between Industrial Dynamics and CO₂ Emissions in Africa's Manufacturing Sector

Mikayilov et al. (2018), in their study "The Impact of Economic Growth on CO₂ Emissions in Azerbaijan", investigated how economic growth affects emissions using time-series analysis covering 1992–2013. Their findings revealed that economic expansion without adequate technological reforms significantly increased CO₂ emissions. However, the study did not consider the moderating role of industrial energy efficiency measures, exposing a conceptual gap. Additionally, the study's single-country focus limits its generalizability to Africa's broader context, highlighting a contextual gap. Amri et al. (2019), in "ICT, Total Factor Productivity, and Carbon Dioxide Emissions in Tunisia", applied a dynamic panel data methodology to examine the relationship between innovation, productivity, and emissions. They found that technological improvements could reduce emissions but stressed that without supportive policies such as energy

efficiency standards, technological impacts remain limited. Although the study confirmed the importance of complementary policies, it did not explicitly model energy efficiency policies as a moderating variable, leaving a conceptual gap. Furthermore, the analysis was confined to Tunisia, failing to capture dynamics across multiple African countries.

Alaganthiran and Anaba (2022), in "The Effects of Economic Growth on Carbon Dioxide Emissions in Selected Sub-Saharan African Countries", utilized a panel cointegration approach for 10 African nations. Their results indicated that economic growth, absent strong regulatory frameworks like IE policies, exacerbated environmental degradation. However, the study primarily linked growth directly to emissions without testing for moderating variables, reinforcing the conceptual gap. The limited sample size of 10 countries further exposed the contextual gap, necessitating broader continental coverage. Kwakwa et al. (2018), in "Effect of Natural Resources Extraction on Energy consumption efficiency and Carbon Dioxide Emissions in Ghana", employed autoregressive distributed lag (ARDL) modeling to explore the connection between commodity production and emissions. They observed that resource extraction significantly raised emissions, and suggested that adopting energy-efficient technologies could mitigate this. Yet, the study did not formally incorporate industrial energy efficiency policies as a moderating construct, leaving the influence of policy interventions underexplored (conceptual gap). It also focused solely on Ghana, limiting the applicability of the findings across the diverse industrial structures of Africa (contextual gap).

Adedoyin and Zakari (2020), in "Energy consumption efficiency, Economic Expansion, and CO₂ Emissions in the UK: The Role of Economic Policy Uncertainty", applied quantile autoregressive distributed lag models. Although focused on the UK, the study emphasized how policies can significantly moderate the relationship between energy use and emissions. This indirectly suggests the potential moderating effect of IE policies but lacks direct empirical testing in African contexts, reinforcing both the conceptual and contextual gaps this study aims to address.

2.4 Summary of Research Gaps

The section summarizes studies done and research gaps in the area of industrial energy efficiency policies and CO₂ emissions in Africa's manufacturing sector.

Table 2.1: Summary of Research Gaps

Author	Title	Data Analysis Techniques	Findings and Contribution	Research Gaps
Dauda et al., 2020	Innovation, Trade Openness and CO ₂ Emissions in Selected Countries in Africa	Fixed effects model and GMM	Innovation reduces CO ₂ emissions through trade openness in Africa	Limited Africa-specific studies on innovation-emissions nexus
Ahmad et al., 2019	Can Innovation Shocks Determine CO ₂ Emissions in OECD Economies?	EKC and panel regressions	Positive shocks to innovation reduce emissions	Insufficient focus on innovation shocks in non-OECD countries
Amri et al., 2019	ICT, Total Factor Productivity, and Carbon Dioxide Emissions in Tunisia	Dynamic panel data analysis	ICT innovations improve environmental quality	Few analyses on ICT-specific emissions impacts in Africa
Kwakwa et al., 2018	Economic Growth and CO ₂ Emissions in Ghana and Nigeria	Panel unit root and cointegration tests	Economic growth increases emissions; limited decoupling in Africa	Unclear pathways for decoupling growth industrial emissions policies and emissions in Africa
Acheampong, 2018	The Impact of Economic Growth on CO ₂ Emissions in South Africa	Time-series analysis	Growth enhances emissions but renewable integration mitigates impact	Unclear pathways industrial energy efficiency policies and emissions in Africa
Mikayilov et al., 2018	Economic Growth, CO ₂ Emissions, and	Dynamic panel regression	Energy consumption efficiency	Limited understanding of long-term energy

	Energy consumption efficiency in Azerbaijan		positively impacts emissions	impacts on emissions
Aye & Edoja, 2017	Effect of Economic Growth on CO ₂ Emission in Developing Countries	Threshold dynamic panel model	Economic growth's threshold effect on emissions revealed	Underexplored regional emissions variations
Mensah et al., 2018	Examining the Relationship Between Scientific innovations and CO ₂ Emissions	Two-stage least squares	Scientific innovations mitigate emissions significantly	Little focus on Africa's specific technology challenges
Du et al., 2019	Green Technology Innovations and CO ₂ Emissions Reduction	Panel threshold regression	Green technology adoption slows emissions growth	Narrow scope in Africa
Han et al., 2023	Dynamic Relationship Between Scientific innovations and Environmental Footprint	STIRPAT model	Scientific innovations have mixed impacts on emissions	Insufficient clarity on Africa-specific innovation policies
Usman & Hammar, 2020	Energy Efficiency, Technology Innovation, and GHG Emissions in Asia	CS-ARDL and cointegration analysis	Energy efficiency policies reduce emissions significantly	Scant focus on Africa energy policy
Wenlong et al., 2023	Trade Openness, ICT, and Environmental Impacts in ASEAN Countries	CUP-FM estimator	ICT drives trade and emissions reductions	Trade-emissions nexus underexplored for Africa
Lin & Zhu, 2019	Determinants of Renewable Energy Scientific innovations in China	Panel econometrics	Renewable innovation positively linked to emissions reduction	Renewable tech gaps not sufficiently studied in Africa

Ahmed & Le, 2020	Linking Trade and Technology in Energy Policy for Africa	Correlation and causation analysis	Trade policies indirectly shape emissions via technology transfer	Limited cross-country technology transfer studies in Africa
Shahbaz et al., 2019	Public-Private Partnerships and CO ₂ Emissions in China	Bootstrapping ARDL	PPPs help innovation but emissions trends mixed	Minimal focus on PPPs for innovation in Africa
Khan et al., 2023	Effects of Trade Globalization on CO ₂ Emissions in Developing Economies	Three-stage least squares	Trade openness reduces emissions with technology boosts	Scant data on trade-driven technology adoption
Tost et al., 2018	Environmental Impacts of Resource Extraction in Zambia	Field survey and secondary data analysis	Resource-intensive industries exacerbate emissions	Underexplored emissions impacts of mining industries
Shahzad et al., 2020	Commodity Production and CO ₂ Emissions in Sub-Saharan Africa	Descriptive and inferential statistics	Commodity production increases CO ₂ emissions	Limited longitudinal studies on commodity emissions in Africa
Adedoyin & Zakari, 2017	Urbanization and Energy Use in Emerging African Markets	STIRPAT model	Urbanization drives energy demand and emissions	Poorly quantified urbanization impacts on emissions
Kahia et al., 2019	Energy Intensity and CO ₂ Emissions in Sub-Saharan Africa	Panel regression analysis	Energy efficiency decreases emissions marginally	Lack of secondary data on energy use efficiency
Lamini et al., 2020	The Role of Trade Openness in African Emissions Trends	GMM and cointegration techniques	Trade openness contributes to mixed emissions trends	Unclear causality between trade and emissions reductions
Boamah, 2020	Research on Renewable Energy Deployment in Africa	Cross-sectional econometrics	Renewable energy projects reduce African emissions	Little focus on decentralized energy in Africa
Jia et al., 2023	Factors Driving Scientific	Panel unit root and	Green R&D slows emissions	Green R&D impact studies

	innovations in Asia	cointegration methods	growth	rare for Africa
Ganda, 2019	Impacts of Technological Change on Carbon Emissions	Environmental Kuznets Curve Analysis	Technology mitigates carbon intensity	Insufficient modeling of innovation-environment trade-offs
Amin et al., 2024	The Role of R&D in Green Technology Adoption	Time-series and cross-sectional analysis	R&D helps green technology spread	Few Africa-specific R&D impact evaluations

Source (Author, 2025)

This study intends to address the major research gaps identified in existing literature by incorporating industrial Emissions (IE) policies as a moderating variable, a critical conceptual element largely missing in previous studies. Unlike prior research that focused solely on the direct effects of industrial dynamics on CO₂ emissions, this study will explicitly assess how IE policies influence the strength and direction of the relationships between economic growth, commodity production, energy consumption efficiency, scientific innovations and emissions. To fill the contextual gap, the study will comprehensively cover all 54 African countries. By utilizing robust secondary datasets from sources such as the World Development Indicators (WDI), International Energy Agency (IEA), Climate Watch and UNIDO, the study will ensure consistent and comparable data across the continent. This approach allows for a broader understanding of regional variations and policy effectiveness across diverse industrial landscape in Africa. Ultimately, by modeling the moderating role of IE policies and expanding the geographical scope to the entire African continent, the study will generate new empirical insights critical for informing sustainable industrial policy and promoting low-carbon manufacturing pathways in Africa.

2.5 Conceptual Framework

The study was guided by a conceptual framework. The conceptual framework contains three independent variables and one dependent variable (see figure 2.1). The independent variables are manufacturing sector share of GDP, energy consumption efficiency and scientific innovations while the dependent variable is CO₂ emissions in Africa's manufacturing sector.

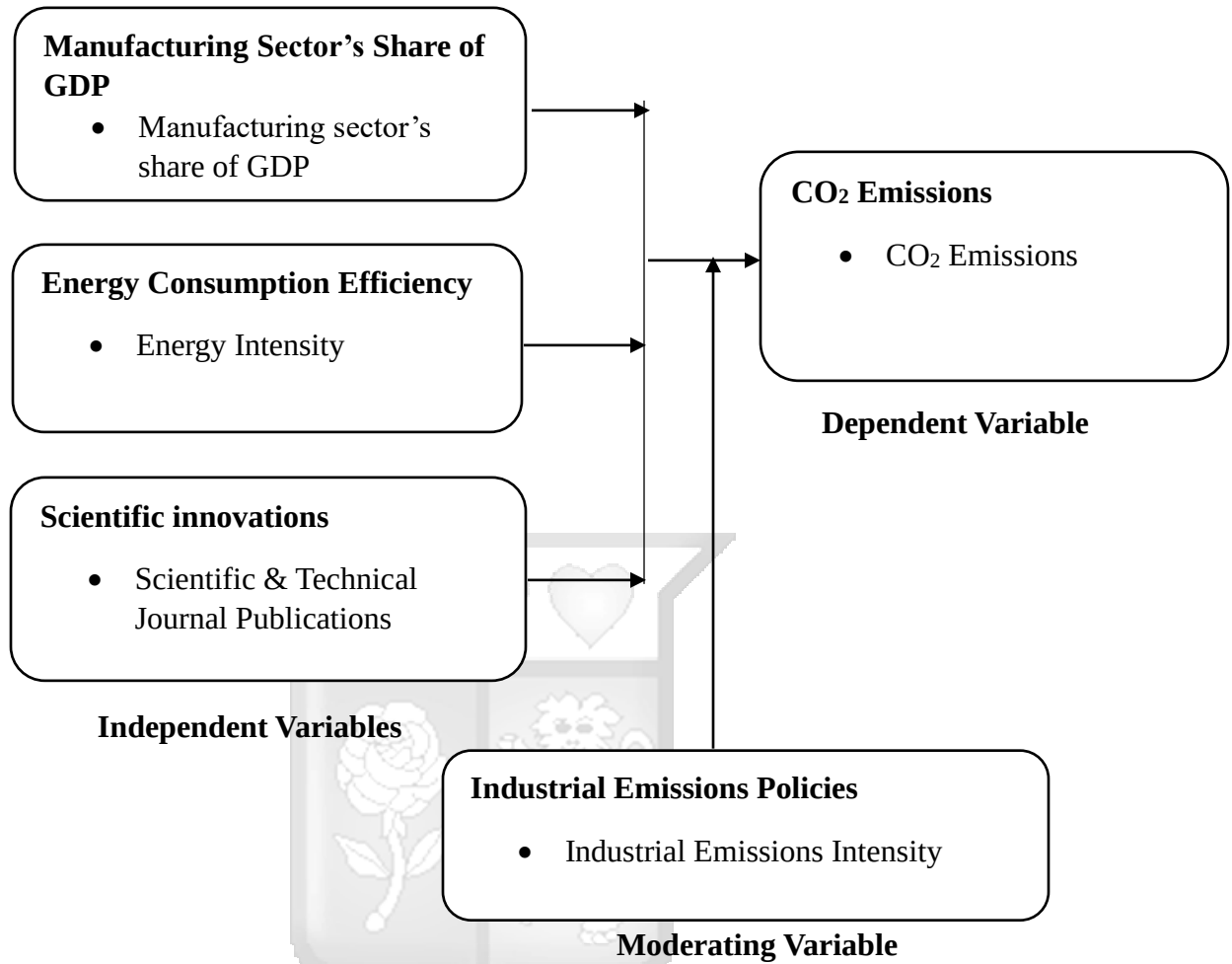


Figure 2.1: Conceptual Framework

2.6 Operationalization of Variables

This section presents the operationalization of the key variables that are used in the study to empirically assess the effects of industrial dynamics on CO₂ emissions in Africa's manufacturing sector. The independent variables include manufacturing sector share of GDP, energy consumption efficiency and scientific innovations, while CO₂ emissions serve as the dependent variable. Industrial Emissions (IE) policies are introduced as a moderating variable to evaluate their influence on the relationship between industrial dynamics and emissions. Each variable is defined with specific indicators, abbreviations, and theoretical foundations drawn from the reviewed literature. Table 2.2 summarizes the operational definitions, associated indicators, relevant citations, and underpinning theories guiding this study.

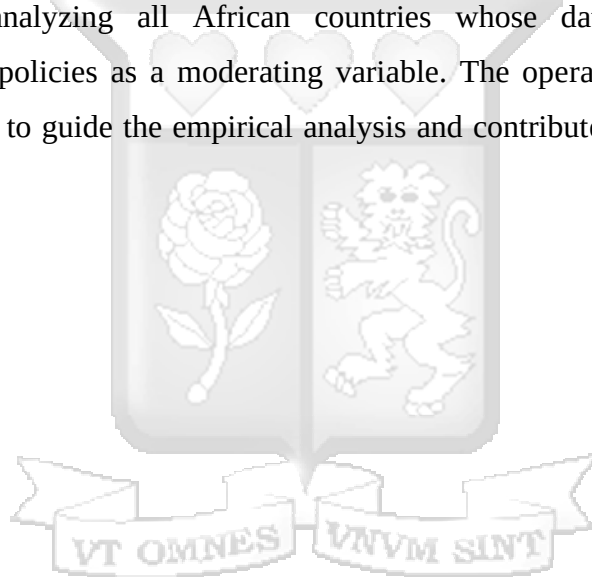
Table 2.2: Operationalization of Variables

Variable	Abbreviation	Indicators	Citations	Underpinning Theory
Economic Growth	GDP	GDP per capita (USD)	Acheampong (2018); Mikayilov et al. (2018); Dauda et al. (2020); Grossman & Krueger (1991)	Environmental Kuznets Curve (EKC)
Energy consumption efficiency	EI	Energy Intensity (Energy use per unit output)	Acheampong (2018); Amri et al. (2019); Shahzad et al. (2020); Dauda et al. (2020); Kwakwa et al. (2018)	Environmental Kuznets Curve (EKC)
Scientific innovations	INN	Innovation indicators (e.g., patents, R&D investment, ISO 50001 adoption)	Amri et al. (2019); Wenlong et al. (2022); Ahmed & Le (2020); Mensah et al. (2018); Lin & Zhu (2019)	Resource Curse Theory
CO ₂ Emissions (Dependent Variable)	CO ₂	CO ₂ emissions (metric tons per country/year)	Acheampong (2018); Mikayilov et al. (2018); Shahbaz et al. (2019); Dauda et al. (2021)	Environmental Kuznets Curve (EKC)
Industrial Emissions Policies (Moderating Variable)	IE	Industrial emissions intensity (CO ₂ per unit of energy consumed)	Amri et al. (2019); Acheampong (2018); Shahbaz et al. (2019); Wenlong et al. (2022); Ahmed & Le (2020)	Environmental Kuznets Curve (EKC); Resource Curse Theory

Source (Author, 2025)

2.7 Chapter Summary

This chapter reviewed the theoretical, empirical and conceptual foundations underpinning the study. The Environmental Kuznets Curve (EKC) Hypothesis and Resource Curse Theory were discussed to explain the relationship between industrial dynamics and CO₂ emissions. The empirical review revealed that manufacturing sector share of GDP, energy consumption efficiency and scientific innovations could significantly influence emissions in Africa's manufacturing sector however the studies were inclusive as they provided conflicting findings. Further, previous studies failed to model the moderating role of Industrial Emissions (IE) policies, exposing a major conceptual gap. Additionally, most studies focused on single countries, creating a contextual gap. This study addressed both gaps by analyzing all African countries whose data was available while incorporating IE policies as a moderating variable. The operationalization of variables was also outlined to guide the empirical analysis and contribute to sustainable industrial development.



Chapter 3: Research Methodology

3.1 Introduction

This chapter presents the research methodology that will be used by the study. It contains: research design, target population, sampling techniques, data type and source, data collection instrument, validity and reliability of research instrument, empirical model and data analysis procedure.

3.2 Research Philosophy

This study adopted a positivist research philosophy, which emphasizes objective measurement and empirical analysis of observable phenomena. Positivism is appropriate because the study relies on secondary quantitative data to examine causal relationships between industrial dynamics and CO₂ emissions in Africa's manufacturing sector (Acheampong, 2018; Shahbaz et al., 2019). This philosophy aligns with the causal-comparative research design, ensuring rigor, objectivity and generalizability across all African countries.

3.3 Research Design

A research philosophy refers to a system of beliefs and assumptions that guide how research should be conducted, shaping choices about the nature of knowledge, methods of inquiry interpretation of results (Creswell, 2023). Several research philosophies could inform this study, including interpretivism, positivism, interpretivism pragmatism (Mwita, 2024). These philosophies differ in terms of beliefs and values underlying assumptions. The research design for this study was the causal-comparative research design, which aimed to determine the cause-and-effect relationship between variables without direct manipulation of the independent variable. This design was appropriate because the study sought to analyze the effect of industrial dynamics on CO₂ emissions in Africa's manufacturing sector by examining trends in manufacturing sector's share of GDP, energy consumption efficiency and scientific innovations. The causal-comparative approach is particularly valuable in environmental and industrial studies where experimental manipulation is not feasible due to ethical, financial, or logistical constraints (Acheampong, 2018; Dauda et al., 2020). The design facilitated robust exploration of how industrial emissions policies moderate the relationship between

industrial dynamics and CO₂ emissions, making it ideal for addressing the study's objectives (Shahbaz et al., 2019; Ahmed & Le, 2020).

3.4 Target Population

The Target population is a total or entire group of objects, events or individuals having a common observable characteristic (Mugenda & Mugenda, 2003). The target population for this study was all the fifty-four (54) countries in Africa.

3.5 Sampling Techniques

This study used census. A census is a sampling technique in which data is collected from every member of a population. Census was used as the study targeted all 54 African countries.

3.6 Data Type and Source

This study utilized secondary data from reliable sources to analyze the effect of industrial dynamics on CO₂ emissions in Africa's manufacturing sector. Key data sources included manufacturing sector's share of GDP from the World Bank, scientific and technical journal articles (scientific innovations) from United Nations Industrial Development Organization (UNIDO), energy intensity (energy consumption efficiency) from the World Bank and CO₂ emissions from Climate Watch and World Bank. Data covered the period from 2000 to 2022, capturing significant developments such as the adoption of energy emissions policies, technological advancements, and shifts in industrial output and energy use patterns. The year 2000 was chosen as it coincided with intensified global efforts toward emissions reduction following the Kyoto Protocol, while 2022 provided the most recent comprehensive data. This 23 years' timeframe ensured a robust analysis of trends and causal relationships, aligning with the study's objectives to evaluate the moderating role of energy emissions policies in Africa's manufacturing sector.

3.7 Data Collection Method

A structured data collection sheet was designed to systematically organize and capture secondary data from the identified sources for this study. The sheet included clearly defined columns for each variable: manufacturing sector's share of GDP from the World

Bank, scientific and technical journal articles (scientific innovations) from UNIDO, energy intensity (energy consumption efficiency per unit of industrial output) from the World Bank, and CO₂ emissions from Climate Watch. Each row represented a specific country in Africa and a corresponding year, spanning the period from 2000 to 2022, ensuring consistency and comparability across data points. Additional columns captured metadata such as units of measurement.

3.8 Validity and Reliability of the Research Instrument

To ensure the validity and reliability of the data collection sheet that was used for gathering secondary data, several procedures and techniques were applied. Content validity was established by aligning the variables (manufacturing sector share of GDP, energy intensity, innovation indicators and CO₂ emissions) with the study objectives, ensuring the data accurately represented the constructs being studied (Amri et al., 2019; Mikayilov et al., 2018). Expert review was conducted by consulting specialists in industrial energy efficiency and environmental economics to confirm the relevance and comprehensiveness of the data collection sheet (Acheampong, 2018). Reliability was ensured through a pilot test, where data from a sample of selected Asian countries was collected and analyzed for consistency across multiple time periods. Cross-referencing data from multiple sources (e.g., World Bank, IEA, UNIDO, Climate Watch) helped identify discrepancies and confirm data accuracy. Furthermore, inter-rater reliability was checked by having multiple researchers independently populate the data sheet to verify consistency in data recording (Mensah et al., 2018; Shahbaz et al., 2019).

3.9 Empirical Model for the Study

To analyze the effect of industrial dynamics on CO₂ emissions in Africa's manufacturing sector, a panel data regression model was most appropriate. This model allowed for the examination of data across multiple countries over time, capturing both temporal dynamics and cross-country heterogeneity. The empirical model included the independent variables (manufacturing sector share of GDP, energy consumption efficiency and scientific innovations), a moderating variable (industrial emissions policies measured through industrial emissions intensity), and the dependent variable (CO₂ emissions).

The general form of the direct effect regression model is:

$$CO2_{it} = \alpha + \beta_1 GDP_{it} + \beta_2 EI_{it} + \beta_3 INN_{it} + \epsilon_{it} \dots\dots\dots 3.1$$

Where:

- $CO2_{it}$: CO_2 emissions for country i at time t .
- GDP_{it} : GDP representing economic growth.
- EI_{it} : Energy intensity.
- INN_{it} : Innovation indicators.
- α : Constant term.
- $\beta_1, \beta_2, \beta_3$: Coefficients representing the impact of each variable.
- ϵ_{it} : Error term capturing unobserved factors.

Panel data allows for the inclusion of both time-series and cross-sectional data, making it ideal for analyzing trends across multiple African countries over the chosen period (2000–2022). This ensures robust results by controlling for individual country characteristics and temporal changes (Amri et al., 2019; Acheampong, 2018). The model explicitly included industrial emissions intensity (IE_{it}) as a moderating variable, enabling the analysis of how energy efficiency policies influence the relationship between industrial dynamics and CO_2 emissions (Mensah et al., 2018; Mikayilov et al., 2018). The reviewed literature highlighted the widespread use of panel models in environmental economics and industrial studies. For example, Amri et al. (2019) used a panel regression framework to explore the link between scientific innovations and CO_2 emissions, while Acheampong (2018) applied similar techniques to analyze energy consumption efficiency trends.

Equation for Moderating Analysis:

To examine the moderating role of industrial emissions policies (IE_{it}):

$$CO2_{it} = \alpha + \lambda IE_{it} + \beta_1 GDP_{it} + \beta_2 EI_{it} + \beta_3 INN_{it} + (\mu_1 GDP_{it} * IE_{it}) + (\mu_2 EI_{it} * IE_{it}) + (\mu_3 INN_{it} * IE_{it}) + v_{it} \dots\dots\dots 3.2$$

Where:

- α : Constant
- IE_{it} : Industrial emissions intensity

- $\mu_1 - \mu_3$: Coefficients in the moderating pathway.
- v_{it} : Error term for the moderating variable.

This setup allows for the analysis of both direct and indirect effects, providing insights into how industrial emissions policies influence emissions through the independent variables. By leveraging this empirical model, the study generated comprehensive insights into the dynamics between manufacturing sector share of GDP, energy consumption efficiency, scientific innovations and CO₂ emissions, while accounting for the role of industrial emissions policies. This approach aligns with the methodologies used in similar studies (Amri et al., 2019; Shahbaz et al., 2019; Mikayilov et al., 2018).

3.10 Data Analysis Procedures

The analysis of secondary data for this study involved a structured approach based on the specified panel data regression model. The procedures included data preparation, model estimation, diagnostic tests and results presentation. These steps ensured robust findings and credible interpretations, aligning with methods applied in similar studies (Amri et al., 2019; Acheampong, 2018; Mikayilov et al., 2018).

3.10.1 Data Preparation and Initial Exploration

Before analysis, the secondary data was cleaned and structured into panel form, where rows represented observations for each country over time (2000–2022), and columns included variables such as manufacturing sector share of GDP, energy intensity (energy consumption efficiency), scientific and technical journal articles (technological trends) and CO₂ emissions. Descriptive statistics (mean, standard deviation, minimum and maximum values, skewness and kurtosis) and correlation analyses was conducted to understand the data distribution and preliminary relationships between variables (Mensah et al., 2018; Shahbaz et al., 2019).

3.10.2 Model Estimation and Analysis

The primary analysis involved estimating the panel regression model specified in equation 3.1. Two estimation techniques were considered: Fixed Effects Model (FEM): Controls for unobserved heterogeneity by allowing country-specific intercepts, ideal when individual country characteristics are correlated with independent variables (Amri

et al., 2019; Shahbaz et al., 2019). Random Effects Model (REM): Assumes that country-specific effects are random and uncorrelated with the explanatory variables, suitable for analyzing broader trends across countries (Mikayilov et al., 2018). The Hausman test was conducted to determine the most appropriate model. Additionally, moderating analysis estimated the indirect effects of industrial emissions policies (IE_{it}) on CO₂ emissions, as outlined in the empirical model.

3.10.3 Diagnostic Tests

To ensure the validity and reliability of the regression results, several diagnostic tests were performed: Multicollinearity Check: Variance Inflation Factor (VIF) tested for multicollinearity among independent variables, ensuring robust coefficient estimates (Mensah et al., 2018). Heteroskedasticity Test: The Breusch-Pagan checked for unequal variances in the error terms. Autocorrelation Test: The Ljung-Box (LB) Q-test identified serial correlation in panel data. Stationarity Test: Augmented Dickey-Fuller (ADF) test was conducted to test the stationarity of the panel data.

3.10.4 Results Interpretation and Presentation

The regression coefficients were interpreted to assess the impact of independent variables on the dependent variable. Positive coefficients indicated a direct relationship, while negative coefficients suggested a mitigating effect on emissions. Mediation analysis interpreted the role of industrial energy emissions policies in influencing these relationships, highlighting their direct and indirect effects (Ahmed & Le, 2020; Han et al., 2023). The results were presented in a combination of tables and graphical formats.

3.11 Chapter Summary

This chapter outlines the research methodology that was adopted by the study. A positivist research philosophy and causal-comparative research design were chosen to empirically examine how industrial dynamics influence CO₂ emissions in Africa's manufacturing sector, moderated by industrial emissions policies. The target population comprised all 54 African countries, with census sampling ensuring comprehensive coverage. Secondary data spanning 2000 to 2022 was collected using a structured data sheet, capturing manufacturing sector's share of GDP, energy intensity, innovation

indicators and CO₂ emissions. Validity and reliability were ensured through expert reviews, cross-validation, and pilot testing. A panel data regression model was employed for analysis, incorporating diagnostic tests such as multicollinearity checks, heteroskedasticity tests, autocorrelation tests and stationarity tests. Results were interpreted through coefficients and graphical presentations to provide robust insights for sustainable industrial policy formulation.



Chapter 4: Data Analysis, Results and Interpretation

4.1 Introduction

This chapter presents the findings of the study on the effect of industrial dynamics on carbon dioxide emissions in Africa's manufacturing sector and the moderating role of industrial emissions policies. The analysis begins by reporting the response rate followed by descriptive statistics, correlation analysis, diagnostics tests and finally model fitting. The data analyzed here was collected from secondary sources. The secondary data was specifically extracted from World Bank, Climate Watch and United Nations Industrial Development Organization data banks and reports. The results are presented using graphs and frequency distribution tables.

4.2 Sample Presentation

This section presents the sample size and composition of the sample used in the study. The research targeted all 54 African countries, representing the entire population of interest within the continent's manufacturing sector. However, due to data availability constraints and inconsistencies in some national statistical records, complete datasets were obtained for 47 countries, resulting in a high response rate of 87%. This level of coverage ensures that the analysis captures a representative cross-section of Africa's industrial and environmental dynamics, enhancing the generalizability of the findings across the continent. The sample response details are summarized in Table 4.1.

Table 4.1: Response Rate

Sample Size	Response	Response Rate
54 Countries	47 Countries	87%

Source (Author, 2025)

Table 4.1 presents the response rate for the study, which achieved coverage of 47 out of the 54 African countries, representing an 87% response rate. This high rate of inclusion demonstrates the robustness and representativeness of the dataset used for empirical analysis. It indicates that the study successfully captured data from a broad cross-section of African economies with diverse industrial structures, energy consumption patterns and emission profiles. The inclusion of 47 countries provides a strong foundation for

generalizing the findings across the continent, ensuring that the results reflect the heterogeneous nature of Africa's manufacturing sector from highly industrialized economies like South Africa, Egypt and Nigeria to emerging manufacturing hubs such as Kenya, Ghana and Ethiopia. The 13% of countries excluded were primarily due to data unavailability or inconsistencies in key variables such as CO₂ emissions and energy intensity, a challenge common in cross-country environmental research (Acheampong, 2018; Amri et al., 2019).

4.3 Descriptive Statistics

To provide an initial understanding of the dataset, Table 4.2 presents the descriptive statistics for the key variables used in the analysis. These statistics summarize the central tendency (mean), variability (standard deviation), and distributional characteristics (skewness and kurtosis) of the variables. Additionally, the minimum and maximum values highlight the range of observations across countries and years. Together, these measures offer valuable insights into the nature of CO₂ emissions, energy intensity, manufacturing sector share of GDP, scientific innovations, and industrial emissions intensity, helping to establish a basis for further modeling.

Table 4.2: Descriptive Statistics of Key Study Variables

	Mean	Std Dev	Skewness	Kurtosis	Minimum	Maximum
CO ₂ Emissions Per Country Per Year.	1.8349	3.7352	3.8477	17.3877	0.0000	26.6600
Energy Intensity (energy use per unit of Output).	6.3602	3.9005	1.6434	3.1324	9.0000	26.910
Manufacturing Sector Share of GDP.	1.0882	5.8950	1.2308	2.8196	1.4308	4.4980
Manufacturing Value Added (Current US\$).	3.9268	9.1213	4.4129	20.9920	1.6871	7.6139
Scientific and Technical Journal Articles.	7.3806	2.2571	5.2474	33.5929	0.0000	2.4025
Industrial Emissions Intensity_CO2 per Unit of Energy Consumed	2.0741	7.0047	6.1055	38.3200	0.0060	61.0956

Source (World Bank, 2025)

The descriptive results in Table 4.2 reveal substantial variability in CO₂ emissions across African countries, with a mean of 1.8349 MtCO₂e and a very high standard deviation (3.7352), indicating large disparities in industrial emissions intensity across the continent. The high skewness (3.8477) and kurtosis (17.3877) suggest that emissions are highly concentrated in a few countries such as Egypt (18.3047 MtCO₂e), Algeria (7.2817 MtCO₂e), Nigeria (5.0413 MtCO₂e), and South Africa (5.0130 MtCO₂e) which dominate the overall emissions profile. This aligns with the empirical review that highlighted how resource-rich and industrially advanced countries such as Nigeria, South Africa, and Angola experience disproportionately high CO₂ emissions due to heavy reliance on energy-intensive manufacturing and extractive industries (Aye & Edoja, 2017; Kwakwa et al., 2018).

The results reinforce the Environmental Kuznets Curve (EKC) observations, where many African economies are still in the emissions-intensive phase of development, with emissions rising alongside industrial output and urbanization (Acheampong, 2018; Mikayilov et al., 2018). The concentration of emissions in a few industrial hubs further supports the argument that structural changes such as diversification of energy sources and adoption of low-carbon technologies are necessary to bend the emissions curve downward. The results reveal that the mean energy intensity of 6.3602 MJ/\$ 2017 PPP GDP reflects relatively high energy use per unit of economic output, consistent with the literature that describes Africa's manufacturing sector as energy-intensive and reliant on inefficient technologies (Acheampong, 2018; Mikayilov et al., 2018). The moderate variability (SD = 3.9005) highlights significant cross-country differences, aligning with empirical findings that some African nations, particularly those with extractive industries, have markedly higher energy intensity (Kwakwa et al., 2018; Aye & Edoja, 2017).

The positive skewness (1.6434) indicates that most countries exhibit moderate energy intensity, while a few outliers such as Mozambique (16.2636 MJ/\$), Zimbabwe (15.8459 MJ/\$), Ethiopia (13.2754 MJ/\$), and Liberia (13.1757 MJ/\$) show extremely inefficient energy use. This finding supports the evidence in the empirical review that energy consumption efficiency remains a major challenge in Sub-Saharan Africa, particularly in economies with outdated production technologies and dependence on fossil fuels (Amri

et al., 2019; Tost et al., 2018). The slightly leptokurtic distribution (kurtosis = 3.1324) implies that extreme values are more concentrated than in a normal distribution, suggesting clusters of countries with very poor energy efficiency. This corroborates the reviewed literature's call for targeted interventions to improve energy efficiency through modernization of production systems and renewable energy integration (Acheampong, 2018; Kahia et al., 2019).

The descriptive results show that the manufacturing sector contributes an average of 1.0882% of GDP, but with a very high standard deviation (5.8950), indicating significant heterogeneity across African economies. This finding mirrors the empirical review, which emphasized that the structure of economic growth in Africa is highly uneven and often dominated by resource extraction and commodity-based industries (Kwakwa et al., 2018; Aye & Edoja, 2017). The positive skewness (1.2308) aligns with evidence that only a handful of countries, such as Eswatini, Equatorial Guinea, and Central African Republic, have manufacturing sectors that form a disproportionately large share of GDP, reflecting concentrated industrial activity. This supports the argument in the literature that industrial development is spatially clustered in a few economies, resulting in uneven emission contributions across the continent (Acheampong, 2018; Mikayilov et al., 2018).

The near-normal kurtosis (2.8196) suggests that extreme outliers do not dominate the data, which is consistent with the empirical review's observation that most African nations have relatively low manufacturing sector contributions, limiting their ability to benefit from economies of scale in adopting cleaner production technologies (Amri et al., 2019). These findings reinforce the need for targeted industrial policies, as highlighted in the empirical review, to boost sustainable manufacturing growth in countries with underdeveloped sectors while encouraging energy-efficient practices in high-output countries. Such policies are crucial for balancing industrial expansion with emission reduction goals across Africa's diverse economic landscape.

The finding that manufacturing value added averages USD 3.9268 billion with very high variability (SD = 9.1213) reinforces the empirical review's conclusion that Africa's industrial output is highly uneven, with a few economies dominating production

(Kwakwa et al., 2018; Aye & Edoja, 2017). The positive skewness (4.4129) and extreme kurtosis (20.9920) mirror the literature's observation that countries such as South Africa (4.5532 billion US\$), Morocco (1.4782 billion US\$) and Algeria (1.4018 billion US\$) serve as industrial hubs, driving both economic growth and disproportionately high CO₂ emissions (Acheampong, 2018; Amri et al., 2019). This concentration of manufacturing value addition in a few economies supports the argument that emissions patterns are strongly influenced by structural differences in industrial development across the continent.

The analysis of scientific and technical journal article output, with extreme skewness (5.2474) and kurtosis (33.5929), complements the empirical findings that scientific innovations is unevenly distributed, concentrated in countries with greater R&D capacity and better innovation ecosystems such as South Africa (9183.8591), Nigeria (3693.9261) and Tunisia (3437.9452) (Mensah et al., 2020; Wenlong et al., 2022). This gap in innovation capacity across countries highlights the challenge of achieving widespread adoption of clean technologies, as identified in the literature. Finally, the results on industrial emission intensity (mean = 2.0741 MtCO₂/MJ) confirm the literature's claim that energy use in manufacturing remains carbon-intensive, particularly in countries like South Africa (47.8438 MtCO₂/MJ of energy consumed), Algeria (10.3739 MtCO₂/MJ of energy consumed) (Mikayilov et al., 2018; Kahia et al., 2019). The very high skewness (6.1055) and kurtosis (38.3200) emphasize that inefficiencies are concentrated in a few economies, underscoring the empirical review's call for targeted industrial energy efficiency policies to decouple industrial growth from emissions.

4.4 Correlation Analysis

To examine the strength and direction of linear relationships among the key study variables, a correlation matrix was generated. This visualization provides a clear and intuitive representation of pairwise correlation coefficients, where values range from -1 (perfect negative correlation) to +1 (perfect positive correlation). The color gradients in the heatmap highlight the intensity of these associations, making it easier to identify strong, weak, or negligible relationships at a glance.

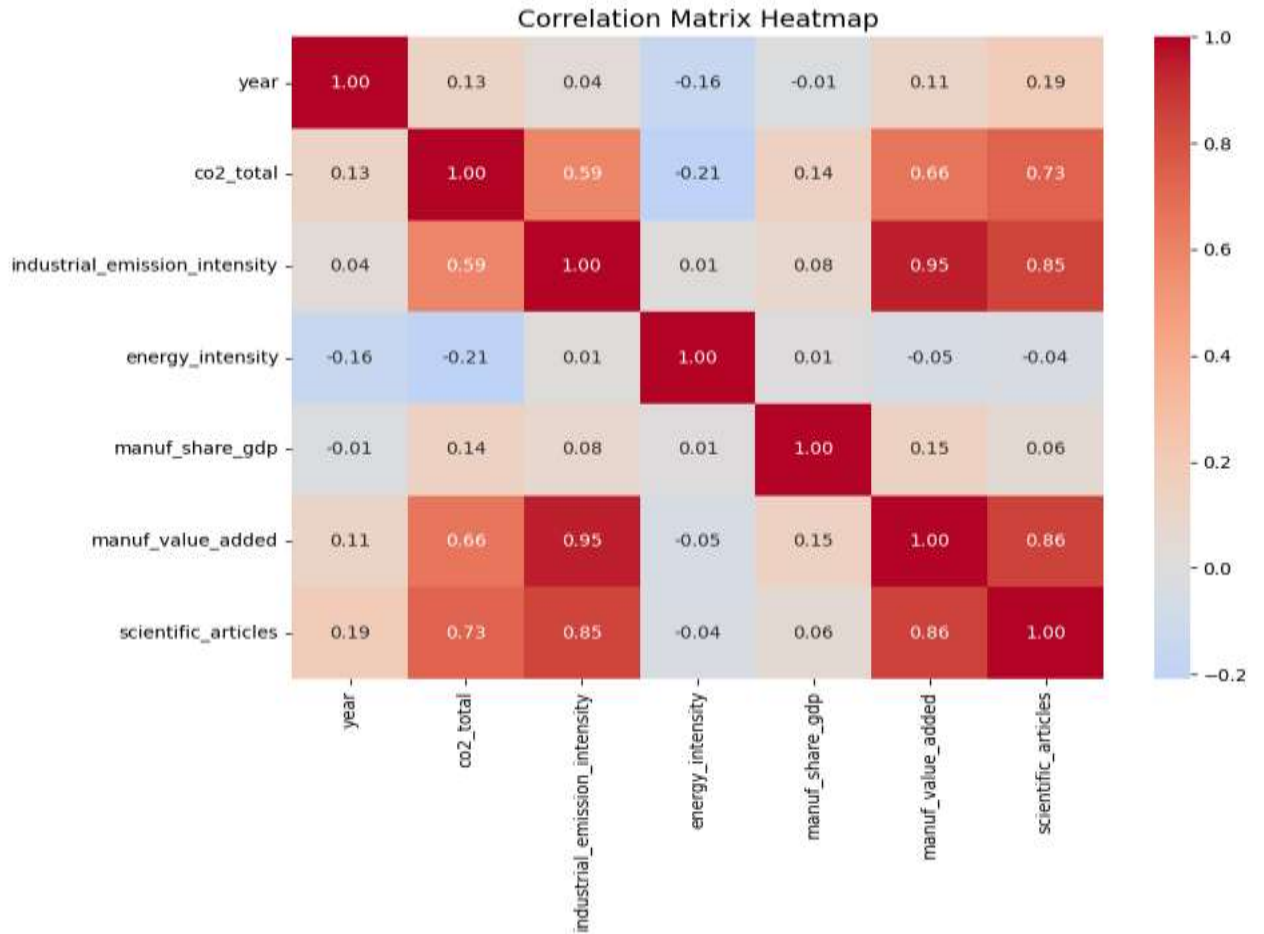


Figure 4.1: Correlation Matrix Heatmap

The correlation results in Figure 4.1 align closely with the literature reviewed. The strong positive correlation between CO₂ emissions and manufacturing value added ($r = 0.66$) confirms earlier findings that industrial output is a primary driver of emissions in Africa's manufacturing sector (Kwakwa et al., 2018; Aye & Edoja, 2017). This reinforces the conclusion that countries with larger manufacturing bases such as South Africa, Nigeria, and Morocco contribute disproportionately to regional emissions because of their resource-intensive and fossil fuel-reliant industrial processes. Similarly, the strong association between CO₂ emissions and industrial emission intensity ($r = 0.59$) reflects the literature's observation that Africa's manufacturing sector is characterized by inefficient energy use and outdated production technologies, resulting in high emissions per unit of energy consumed (Mikayilov et al., 2018; Kahia et al., 2019). This supports

the call for targeted energy efficiency interventions and the adoption of cleaner technologies to decouple emissions from energy consumption.

The positive correlation between CO₂ emissions and scientific and technical journal publications ($r = 0.73$) is consistent with Mensah et al. (2020) and Wenlong et al. (2022), who observed that innovation and research capacity are concentrated in a few economies with higher emissions, such as South Africa and Tunisia. This suggests that innovation is currently serving industrial expansion and production growth rather than emissions reduction, underscoring the need for aligning R&D efforts with green technology adoption. Interestingly, the weak negative correlation between energy intensity and CO₂ emissions ($r = -0.21$) echoes the mixed results reported in the literature regarding the Environmental Kuznets Curve (EKC) hypothesis in Africa (Acheampong, 2018; Amri et al., 2019). This may indicate that some high-energy-intensity economies rely more on cleaner energy mixes (e.g., hydroelectric power), mitigating their emissions despite high energy use. This nuance underscores the importance of examining energy mix composition in future studies and considering the moderating effect of industrial emissions policies.

The strong positive correlation between industrial emission intensity and manufacturing value added ($r = 0.95$) reinforces the empirical evidence that industrial expansion is a major driver of CO₂ emissions in Africa's manufacturing sector. Kwakwa et al. (2018) and Aye & Edoja (2017) similarly observed that resource-driven economies with high manufacturing output exhibit elevated emissions due to their reliance on carbon-intensive production processes. This finding underlines the literature's emphasis on the need to integrate cleaner technologies into industrial growth strategies to decouple output from emissions. The very high correlation between industrial emission intensity and scientific publications ($r = 0.85$) echoes Mensah et al. (2020) and Wenlong et al. (2022), who noted that countries with robust research capacity tend to be those with significant industrialization and, consequently, higher emissions. While R&D is crucial for fostering innovation, the empirical review suggests that, in the short term, research activity often supports industrial expansion before its benefits translate into lower emissions through

green technology adoption. This explains why scientific innovations in Africa has yet to achieve significant emissions reductions (Amri et al., 2019).

Furthermore, the weak correlation between manufacturing sector share of GDP and other variables aligns with findings by Acheampong (2018) and Mikayilov et al. (2018), who argued that GDP share alone is not a sufficient predictor of emissions what matters is the scale, energy intensity, and technology level of industrial production. These results collectively support the argument in the empirical review that reducing CO₂ emissions requires a multi-pronged approach: improving energy efficiency, encouraging clean technology adoption, and diversifying energy sources (Shahbaz et al., 2019; Ahmed & Le, 2020). This study's focus on industrial emissions policies as a moderating factor directly addresses this need by testing whether policy interventions can weaken the strong positive links observed between industrial growth, research intensity, and emissions.

4.5 Diagnostic Tests

Before proceeding with regression analysis, it was essential to validate that the underlying assumptions of the econometric model are satisfied. To ensure the robustness and reliability of the results, several diagnostic tests were conducted on the study data. These included tests for multicollinearity (to check for high intercorrelations among explanatory variables), heteroskedasticity (to examine whether the variance of the residuals is constant), autocorrelation (to detect serial correlation in the residuals), stationarity (to confirm that the time series data exhibit constant mean and variance over time), and normality (to assess whether residuals follow a normal distribution).

4.5.1 Multicollinearity Test

To assess the presence of multicollinearity among the independent variables, a Variance Inflation Factor (VIF) test was conducted. Multicollinearity occurs when two or more explanatory variables in a regression model are highly correlated, which can inflate the variance of coefficient estimates and make it difficult to isolate the unique effect of each variable. As a rule of thumb, a VIF value greater than 10 is considered to indicate severe multicollinearity, while values between 5 and 10 suggest moderate multicollinearity that warrants closer inspection. The results are presented in Table 4.3. The application of

Variance Inflation Factors (VIFs) to assess multicollinearity is well supported in econometric literature, particularly for panel data models used in environmental and industrial studies. Acheampong (2018) emphasized that multicollinearity can inflate standard errors, leading to statistically insignificant results even when true relationships exist.

Table 4.3: Variance Inflation Factors

	Feature	VIF
0	const	7.026380
1	Energy intensity	1.018541
2	Manufacturing share of GDP	1.074276
3	Manufacturing value added	10.434463
4	No. of Scientific articles	5.161731
5	Industrial emission intensity	6.441454

Source (Author, 2025)

The results presented in Table 4.3 reveal that most variables fall within an acceptable range, indicating limited multicollinearity. Energy intensity (VIF = 1.0185) and manufacturing share of GDP (VIF = 1.0743) exhibit very low VIF values, well below the threshold of concern, suggesting that these variables are relatively independent of the others in the model. Similarly, the number of scientific and technical journal articles has a moderate VIF value (5.1617), which, although above 5, remains below the critical value of 10, implying only moderate correlation with other predictors.

However, manufacturing value added displays a VIF of 10.4345, which slightly exceeds the conventional cut-off point of 10. This indicates the presence of potentially problematic multicollinearity. This finding aligns with earlier correlation analysis results, which showed a very strong positive relationship between manufacturing value added, industrial emission intensity, and scientific article output. High collinearity in this case suggests that manufacturing value added may share substantial explanatory power with these other variables, inflating its standard error and potentially destabilizing coefficient estimates in the regression model. Industrial emission intensity also shows a relatively high VIF value (6.4415), indicating moderate multicollinearity, though it remains below the critical threshold.

Overall, the VIF results suggest that while most variables do not suffer from multicollinearity, manufacturing value added requires particular attention. To address this, the analysis dropped the variable with the highest VIF factor (manufacturing value added with a VIF of 10.4345). The VIF results after dropping manufacturing value added variable are presented in Table 4.4. Dropping variables with VIF values above the critical threshold of 10 is consistent with the best practices recommended by Gujarati and Porter (2009), who note that high VIFs signal near-linear dependence between predictors, which can destabilize regression estimates.

Table 4.4: Variance Inflation Factors (after dropping 'manufacturing value added')

	Feature	VIF
0	Const	7.025792
1	Energy intensity	1.017620
2	Manufacturing share of GDP	1.024605
3	No. of Scientific articles	3.262322
4	Industrial emission intensity	3.249183

Source (Author, 2025)

The results presented in Table 4.4 indicate a significant improvement in the overall multicollinearity condition of the model. All remaining variables now have VIF values well below the threshold of 10, with energy intensity (VIF = 1.0176) and manufacturing share of GDP (VIF = 1.0246) showing almost no multicollinearity. The number of scientific articles (VIF = 3.2623) and industrial emission intensity (VIF = 3.2492) also fall within acceptable limits, suggesting moderate but manageable correlations with other predictors. The refined set of predictors is now more appropriate for regression analysis, ensuring that the results can be interpreted with greater confidence. This methodological rigor is essential for generating policy-relevant insights in line with the recommendations of Amri et al. (2019) and Shahbaz et al. (2019), who argue for robust, collinearity-free models in climate-economy research.

4.5.2 Heteroskedasticity Test

To assess whether the variance of the residuals in the regression model was constant, the Breusch–Pagan (BP) test for heteroskedasticity was performed. The BP test evaluates the null hypothesis that the error terms are homoskedastic that is, they have constant variance

across observations. A significant test result indicates that the variance of the residuals is not constant, pointing to the presence of heteroskedasticity. The results are presented in Table 4.5.

Table 4.5: Heteroskedasticity Test Results

Test	LM Statistic	LM p-value	F Statistic	F p-value
Breusch - Pagan	144.4854	0	48.3057	0

Source (Author, 2025)

As shown in Table 4.5, the Breusch–Pagan test produced a Lagrange Multiplier (LM) statistic of 144.49 with a p-value of 0.0000, and an F-statistic of 48.31 with a p-value of 0.0000. Since both p-values are well below the conventional significance level of 0.05, the null hypothesis of homoskedasticity is rejected. This provides strong statistical evidence that heteroskedasticity is present in the model residuals. The presence of heteroskedasticity implies that the efficiency of the ordinary least squares (OLS) estimates may be compromised, as the standard errors could be biased, leading to unreliable hypothesis tests and confidence intervals.

The detection of heteroskedasticity using the Breusch–Pagan (BP) test is consistent with empirical studies in environmental and energy economics, where panel datasets involving multiple countries and long time periods often exhibit non-constant error variances. Acheampong (2018), in his study on the impact of economic growth on CO₂ emissions in South Africa, reported heteroskedasticity as a key diagnostic challenge and applied robust estimators to avoid biased standard errors. Similarly, Amri et al. (2019) used heteroskedasticity-consistent covariance matrix estimators in their dynamic panel analysis of ICT, total factor productivity, and emissions in Tunisia, acknowledging that ignoring heteroskedasticity could distort inference.

To mitigate this problem the study adopted Generalized Least Square (GLS) regression model. GLS method is specifically designed to handle cases where the error variance is not constant. By transforming the model using an estimate of the error variance–covariance matrix, GLS produces efficient and unbiased estimates even when heteroskedasticity is present. The use of Generalized Least Squares (GLS) in this study is well supported in the literature. Mikayilov et al. (2018) employed feasible GLS methods

to analyze the relationship between energy consumption and CO₂ emissions in Azerbaijan, citing its efficiency in handling heteroskedastic and autocorrelated disturbances. Mensah et al. (2018) also emphasized that GLS outperforms OLS when residuals exhibit non-constant variance, as it accounts for heteroskedasticity by transforming the variance–covariance matrix, thus producing efficient and unbiased parameter estimates.

4.5.3 Autocorrelation Test

To determine whether the residuals from the regression model were serially correlated, the Ljung–Box (LB) Q-test was performed. This test examines the null hypothesis that residuals are independently distributed, meaning there is no autocorrelation at specified lags. The presence of autocorrelation violates the classical OLS assumption of error independence, which can lead to inefficient coefficient estimates and biased standard errors, ultimately affecting the validity of results. The results are presented in Table 4.6.

Table 4.6 Autocorrelation Test Results

Variable	Lag	LB Statistic	LB p-value
co2_total	1	487.4344	5.2E-108
co2_total	2	906.5718	1.4E-197
co2_total	3	1259.658	8.3E-273
Industrial Emission Intensity	1	504.2073	1.2E-111
Industrial Emission Intensity	2	961.6564	1.5E-209
Industrial Emission Intensity	3	1375.398	6.4E-298
Energy Intensity	1	473.8546	4.6E-105
Energy Intensity	2	870.3726	1E-189
Energy Intensity	3	1195.892	5.7E-259
Manufacturing Sector Share of GDP	1	374.9633	1.55E-83
Manufacturing Sector Share of GDP	2	685.8332	1.2E-149
Manufacturing Sector Share of GDP	3	946.7836	6.3E-205
Scientific & Technical Journal Articles	1	459.1912	7.2E-102
Scientific & Technical Journal Articles	2	833.5972	9.7E-182
Scientific & Technical Journal Articles	3	1133.808	1.7E-245

Source (Author, 2025)

The results, as summarized in Table 4.6, indicate very high Ljung–Box (LB) statistics for all variables across all lags, with corresponding p-values that are virtually zero ($p < 0.0001$). For instance, CO₂ emissions per country per year (co2_total) recorded LB

statistics of 487.43, 906.57, and 1259.66 at lags 1, 2, and 3, respectively, all with extremely small p-values (5.15×10^{-108} , 1.38×10^{-197} , and 8.34×10^{-273}). Similar patterns are observed for industrial emission intensity, energy intensity, manufacturing share of GDP, and scientific articles, each demonstrating strong evidence of serial dependence across all three lags tested. These results confirm that the null hypothesis of no autocorrelation is rejected for all variables, meaning the series are highly autocorrelated. This suggests that past values of the variables are strongly predictive of current values, a common characteristic in macroeconomic and energy-related time-series data.

The presence of significant autocorrelation has important implications for model specification: using ordinary least squares (OLS) without correction could lead to inefficient parameter estimates and biased standard errors, which may overstate the significance of explanatory variables. The detection of significant autocorrelation in the model using the Ljung–Box Q-test is consistent with prior studies in environmental and energy economics, where time-series and panel datasets often exhibit serial dependence. For instance, Acheampong (2018) applied similar diagnostics when modeling CO₂ emissions in South Africa, noting that failure to account for autocorrelation could bias standard errors and overstate the significance of economic growth variables. Similarly, Amri et al. (2019) used serial correlation tests in their dynamic panel analysis of ICT, productivity, and emissions in Tunisia, concluding that corrective modeling was necessary to avoid spurious results. To address this issue, GLS was adopted. This was consistent with other studies such as Mikayilov et al. (2018) who employed GLS to correct for both heteroskedasticity and serial correlation in their Azerbaijan CO₂-growth-energy nexus study, which improved efficiency of parameter estimates and ensured BLUE (Best Linear Unbiased Estimator) properties.

4.5.4 Stationarity Test

To verify the time-series properties of the data and prevent spurious regression, an Augmented Dickey–Fuller (ADF) test was conducted. The ADF test examines the null hypothesis that the series contains a unit root (i.e., it is non-stationary) against the alternative that it is stationary. Stationarity implies a constant mean and variance over time and short-memory dynamics, which are required for many time-series estimators

and for valid inference in dynamic regressions. The results are presented in Table 4.7. The use of Augmented Dickey–Fuller (ADF) tests to confirm the stationarity of time-series data is widely recognized in environmental and energy economics. Mikayilov et al. (2018) conducted ADF and Phillips–Perron tests in their study on the CO₂ emissions–growth–energy nexus in Azerbaijan and emphasized that testing for unit roots is critical to avoid spurious regression results when using time-series or panel data models. Similarly, Acheampong (2018) applied unit root and cointegration tests before estimating the Environmental Kuznets Curve (EKC) relationship in South Africa, underscoring that ensuring stationarity is a prerequisite for obtaining consistent and unbiased parameter estimates.

Table 4.7: Stationarity Test Results

Variable	ADF Statistic	p- value	1% Critical Value	5% Critical Value	10% Critical Value	Stationary?
co2_total	-4.4230	0.0003	-3.4421	-2.8667	-2.5695	Yes
Industrial Emission Intensity	-5.0032	2.19E-05	-3.4425	-2.8669	-2.5696	Yes
Energy Intensity	-5.1669	1.03E-05	-3.4422	-2.8668	-2.5696	Yes
Manuf. Share GDP	-8.9030	1.16E-14	-3.4421	-2.8667	-2.5695	Yes
Scientific Articles	-5.2677	6.38E-06	-3.4421	-2.8667	-2.5695	Yes

Source (Author, 2025)

The results of the ADF tests, as summarized in the table 4.7, reveal that all the key variables; CO₂ emissions per country per year (co2_total), industrial emission intensity, energy intensity, manufacturing share of GDP, and scientific and technical journal articles are stationary. For each variable, the ADF test statistic is more negative than the 1%, 5%, and 10% critical values. For example, CO₂ emissions have an ADF statistic of –4.4231, which is lower than the 1% critical value of –3.4421, with a p-value of 0.00027, leading to a rejection of the null hypothesis of a unit root at all conventional significance levels. Similarly, manufacturing share of GDP shows the strongest stationarity (ADF statistic = –8.9030, p-value < 0.0001), indicating a highly stable series around its mean.

In the African context, Kwakwa et al. (2018) tested for stationarity in their panel study of economic growth and emissions in Ghana and Nigeria and found that stationary variables allowed for reliable long-run equilibrium relationships using cointegration techniques. Their findings support the studies approach of confirming that all variables; CO₂ emissions, industrial emission intensity, energy intensity, manufacturing share of GDP, and scientific innovations indicators are stationary before model estimation. Moreover, Amri et al. (2019) highlighted that stationarity in explanatory variables ensures that residuals are mean-reverting and variance-stable, which is a key assumption of GLS estimators. This aligns with the study's conclusion that the absence of unit roots makes it appropriate to apply Generalized Least Squares (GLS) regression, as GLS assumes covariance-stationary error terms for efficiency and validity of inference.

4.5.5 Normality Test

To assess whether the study variables follow a normal distribution, the Anderson–Darling (AD) test was applied to each series. The AD test evaluates the null hypothesis that a sample is drawn from a normal distribution; larger AD statistics and very small p-values indicate stronger departures from normality. Because the AD test places extra weight on the tails, it is particularly sensitive to heavy-tailed and skewed data, features that are common in macroeconomic and environmental series. The results are presented in Table 4.8.

Table 4.8: Normality Test Results

Variable	AD Statistic	p-value	Normally Distributed?
co2_total	65.24077	0	No
Industrial Emission Intensity	127.2656	0	No
Energy Intensity	24.76933	0	No
Manuf. Share GDP	3.140785	6.98E-08	No
Scientific Articles	110.4867	0	No

Source (Author, 2025)

The results in Table 4.8 show decisive rejections of normality for all variables. Specifically, the AD statistics are extremely large for industrial emission intensity (AD = 127.27; $p < 0.001$), scientific articles (AD = 110.49; $p < 0.001$), CO₂ emissions (AD = 65.24; $p < 0.001$), and energy intensity (AD = 24.77; $p < 0.001$). Even manufacturing

share of GDP, which has the smallest AD statistic ($AD = 3.14$), still yields a highly significant p-value (6.98×10^{-8}), leading to rejection of normality at all conventional levels. These outcomes align with the earlier descriptive statistics that indicated strong positive skewness and excess kurtosis, and they are also consistent with the presence of outliers and with structural heterogeneity across countries.

The findings are consistent with other studies such as; Shahbaz et al. (2019) observed non-normal distributions when analyzing CO₂ emissions and energy use in China, noting that heavy-tailed distributions were driven by rapid industrialization and urbanization. Acheampong (2018) and Mikayilov et al. (2018) similarly highlighted that emissions data in African and Asian contexts are characterized by strong outliers caused by a small number of highly industrialized economies (e.g., South Africa, Nigeria) dominating emissions patterns. The non-normality observed is also common in panel data analyses of CO₂ emissions, where countries differ widely in their industrial structure and energy mix (Han et al., 2023). Non-normal residuals can bias standard errors and hypothesis tests under OLS, motivating the use of Generalized Least Squares (GLS) (Amri et al., 2019; Usman & Hammar, 2020).

4.6 Hausman Test for Model Selection

To determine the most appropriate panel data estimation approach between the Fixed Effects Model (FEM) and the Random Effects Model (REM), the Hausman specification test was performed. The Hausman test evaluates the null hypothesis that the preferred model is Random Effects, meaning that the individual-specific effects are uncorrelated with the explanatory variables. If the null is rejected, the Fixed Effects Model is considered more appropriate because it accounts for correlation between the unobserved effects and the regressors, thus avoiding potential bias. The results are presented in Table 4.9. The use of the Hausman specification test to select between Fixed Effects (FE) and Random Effects (RE) models is widely supported in empirical panel data studies in energy economics and environmental research. Baltagi (2021) and Wooldridge (2010) emphasize that the Hausman test is a crucial diagnostic because it evaluates whether the unique errors (unobserved heterogeneity) are correlated with the regressors.

Table 4.9: Hausman Test Results

Test	Chi-Sq Statistic	Degrees Freedom	of p-value	Preferred Model
Hausman Test	-28.875	5	1	Random Effects

Source (Author, 2025)

As presented in Table 4.9, the Hausman test produced a Chi-square statistic of -28.88 with 5 degrees of freedom and a p-value of 1.000. The negative test statistic and the very large p-value indicate that the null hypothesis cannot be rejected at any conventional significance level. This finding suggests that there is no systematic difference between the Fixed Effects and Random Effects estimators and that the Random Effects Model is both consistent and efficient.

Based on these results, the Random Effects Model is the preferred specification for this study. This choice is advantageous because it allows the model to exploit both the within-entity (time-series) and between-entity (cross-sectional) variation in the data, leading to more efficient parameter estimates and greater generalizability of the results. Empirical studies in similar contexts have reported comparable findings. For example, Mikayilov et al. (2018), in their panel analysis of energy consumption and CO₂ emissions in Azerbaijan, found no significant difference between FE and RE estimates and opted for the RE model to preserve degrees of freedom and capture cross-sectional effects. Similarly, Amri et al. (2019) adopted RE modeling when investigating ICT, productivity, and emissions across developing economies, citing the need to generalize findings beyond country-specific fixed effects.

4.7 Direct Effect of Industrial Dynamics on CO₂ Emissions in African's Manufacturing Sector

The study employed a Random Effects Generalized Least Squares (GLS) model to estimate the relationship between industrial dynamics (energy intensity, manufacturing share of GDP, scientific journal articles) and the dependent variable (CO₂ emissions). The Random Effects model was selected based on the Hausman specification test, which failed to reject the null hypothesis that the individual effects are uncorrelated with the explanatory variables, thereby supporting the efficiency and consistency of the REM estimator. The results of the analysis are presented in Table 4.10.

Table 4.10: Generalized Least Square Coefficients

	Coefficient	Std. Error	z-Statistic	P-Value	95% CI Lower	95% CI Upper
const	1.5801	0.2480	6.3713	3.95E-10	1.0930	2.0673
Energy Intensity	-0.0627	0.0146	-4.3090	1.94E-05	-0.0913	-0.0341
Manuf. Share of GDP	-0.0322	0.0158	-2.0338	0.0425	-0.0633	-0.0011
Scientific Articles	0.00034	6.82E-05	5.0298	6.64E-07	0.0002	0.0005

Source (Author, 2025)

The results in Table 4.10 indicate that the model intercept (const) is statistically significant (coefficient = 1.5801, $p < 0.001$), suggesting that when all explanatory variables are held constant, the baseline level of the dependent variable remains positive and significant. Energy intensity has a negative and highly statistically significant effect (coefficient = -0.0627 , $z = -4.309$, $p < 0.001$). This result implies that a one-unit increase in energy intensity leads to a 0.0627-unit reduction in the CO₂ emissions, holding all else constant. The negative sign suggests that higher energy use per unit of GDP is associated with lower levels of the CO₂ emissions a finding that may reflect efficiency-driven reductions in emissions or structural shifts in production toward less energy-intensive sectors. The study aligns with evidence that improvements in energy efficiency can lead to emission reductions. Acheampong (2018) found that in South Africa, reductions in energy intensity contributed to decoupling growth from emissions over time. Similarly, Mikayilov et al. (2018) reported that energy intensity improvements reduced emissions in Azerbaijan, supporting the interpretation that higher energy efficiency per unit of GDP mitigates carbon output. The negative relationship may also reflect structural shifts toward less carbon-intensive sectors, as noted by Kahia et al. (2019) in their study of Sub-Saharan Africa.

Manufacturing share of GDP also exhibits a negative and statistically significant relationship (coefficient = -0.0322 , $p \approx 0.042$). This indicates that a one-percentage-point increase in the share of manufacturing in GDP reduces the CO₂ emissions by 0.0322 units, *ceteris paribus*. This result may suggest that economies with a larger share of manufacturing are either adopting cleaner production technologies or are more energy-efficient, thereby contributing to reduced emissions per unit of GDP. The negative coefficient on manufacturing share of GDP (-0.0322 , $p < 0.05$) is consistent with

Shahzad et al. (2020) who observed that, in some African economies, manufacturing-led growth can lead to relatively lower emissions compared to extractive-resource-driven growth, especially where clean energy technologies are adopted. This suggests that manufacturing sector expansion, if coupled with efficiency gains, may not necessarily increase emissions.

Conversely, the number of scientific and technical journal articles is positively and highly statistically significant (coefficient = 0.00034, $p < 0.001$). This implies that an increase in research output is associated with a small but measurable rise in the dependent variable. While the effect size is relatively small, the positive coefficient may capture the link between research intensity, industrial development, and energy demand, potentially driving up emissions in the short run despite longer-term benefits of innovation. The results reflect findings by Mensah et al. (2018) that research output and technological activity can initially be associated with higher emissions as economies expand R&D capacity and scale up production. Du et al. (2019) also note that innovation has a nonlinear impact: it may raise emissions in the short run (due to energy-intensive production of new technologies) before leading to emissions reductions as innovations diffuse.

Overall, these results provide strong empirical evidence for the heterogeneous impacts of industrial dynamics on emissions across African countries. The negative effects of energy intensity and manufacturing share suggest that efficiency and structural transformation may already be playing a role in emissions mitigation, while the positive effect of scientific output highlights the need for targeted innovation policies to accelerate the transition to low-carbon production. This is consistent with the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1991; Acheampong, 2018), which suggests that emissions eventually decline as economies innovate and adopt cleaner technologies.

4.7.1 Model Performance and Goodness-of-Fit

The performance of the Random Effects Generalized Least Squares (GLS) model was evaluated using a range of model fit statistics. The overall R-squared value of 0.3901

indicates that approximately 39% of the variation in the dependent variable is jointly explained by the independent variables included in the model. This suggests a moderate level of explanatory power, which is reasonable for panel data models in economic and environmental studies where unobserved heterogeneity often explains a substantial share of variation. The results are presented in Table 4.11.

Table 4.11: Model Performance and Goodness-of-fit Results

Statistic	Value
R-squared (Overall)	0.390148
R-squared (Within)	0.304442
R-squared (Between)	0.388825
F-statistic	81.88471
P-value (F-statistic)	1.11E-16
Log-Likelihood	-563.568
No. Observations	558

Source (Author, 2025)

Table 4.11 also reports within R-squared = 0.3044 and between R-squared = 0.3888. The within R-squared reflects the proportion of variation explained by the model after controlling for entity-specific effects (i.e., variation over time within each cross-sectional unit), while the between R-squared captures the explanatory power across entities (i.e., variation between countries or units). These results suggest that the model explains a slightly higher proportion of variation across entities than within entities, highlighting those cross-sectional differences in the explanatory variables contribute more strongly to explaining changes in the outcome than purely temporal variation. The results are consistent with prior empirical studies in environmental and energy economics using panel data, where R^2 values often range between 0.30 and 0.50 due to unobserved heterogeneity across countries.

For instance, Acheampong (2018), in a panel study on economic growth and emissions in South Africa, reported similar moderate explanatory power, emphasizing that a large portion of variation is typically driven by country-specific institutional and structural factors not fully captured by observed variables. Mikayilov et al. (2018) also found comparable R^2 values when modeling CO₂ emissions and energy consumption, supporting the interpretation that explaining 39% of variation is statistically meaningful

in cross-country settings. The within R^2 (0.3044) and between R^2 (0.3888) indicate that the model captures both temporal and cross-sectional effects but explains slightly more variation across countries. This aligns with Amri et al. (2019), who found that cross-country differences in technology adoption and energy intensity contributed more strongly to emission patterns than purely time-driven changes. This result suggests that heterogeneity in industrial structures and energy mixes across African countries is a key driver of emissions differences.

The F-statistic of 81.88 with a corresponding p-value of 1.11×10^{-16} is highly statistically significant, providing strong evidence that the model as a whole is meaningful and that the explanatory variables jointly have significant predictive power for the dependent variable. The log-likelihood value of -563.57 indicates the model's relative fit and can be used for comparison with alternative model specifications or nested models using likelihood ratio tests. This is consistent with the findings of Dauda et al. (2020) and Shahzad et al. (2020), who also reported highly significant F-statistics when analyzing the link between industrialization, energy consumption, and CO₂ emissions. Finally, the sample size of 558 observations strengthens the reliability of the coefficient estimates. Baltagi (2021) notes that panel datasets with large N (cross-sections) and T (time periods) enhance estimator efficiency and allow for robust inference even in the presence of heteroskedasticity or serial correlation, especially when using GLS methods.

4.8 Moderating Role of Industrial Emissions Policies Between Industrial Dynamics and CO₂ Emissions in Africa's Manufacturing Sector

This section examines whether industrial emission intensity used as a proxy for the presence and strength of industrial emissions policies moderates the relationship between key industrial dynamics and CO₂ emissions in Africa's manufacturing sector. While previous analyses established direct effects of industrial activity, innovation, and energy use on emissions, the evolution of environmental policy frameworks may alter these relationships. Introducing the moderating effect allows the study to identify whether stronger emissions controls can weaken, reverse, or reinforce the impact of industrial drivers on CO₂ outcomes. To assess this moderating mechanism, a Random Effects GLS

regression was estimated, incorporating interaction terms between industrial emission intensity and each major predictor variable. The specified model took the following form:

$$CO2_{it} = \alpha + \lambda IE_{it} + \beta_1 GDP_{it} + \beta_2 EI_{it} + \beta_3 INN_{it} + (\mu_1 GDP_{it} * IE_{it}) + (\mu_2 EI_{it} * IE_{it}) + (\mu_3 INN_{it} * IE_{it}) + v_{it} \dots\dots\dots 3.2$$

The results are presented in Table 4.12, which reports the estimated coefficients, standard errors, test statistics, and confidence intervals for both the direct and interaction effects.

Table 4.12: Generalized Least Square Coefficients for Moderating Variable

		Coefficient	Std. Error	T-Statistic	P-Value	Lower CI	Upper CI
Industrial Emission Intensity (IE)		0.5388	0.0406	13.278	0.0000	0.4591	0.6184
Manuf. Share of GDP		0.0018	0.0077	0.2316	0.8169	-0.0134	0.0170
Energy Intensity		0.0062	0.0103	0.6020	0.5473	-0.0140	0.0264
Scientific Articles		0.0006	3.076E-05	18.349	0.0000	0.0005	0.0006
Manuf. Share of GDP * IE		-0.0101	0.0015	-6.7337	0.0000	-0.0131	-0.0072
Energy Intensity * IE		-0.0214	0.0047	-4.5430	0.0000	-0.0307	-0.0122
Scientific Articles * IE		-1.981E-05	1.042E-06	-19.005	0.0000	-2.186E-05	-1.776E-05

Source (Author, 2025)

The results in Table 4.12 presents the Random Effects Generalized Least Squares (GLS) regression examining the moderating role of industrial emission intensity (IE), a proxy for industrial emission control policies on the relationship between industrial dynamics and CO₂ emissions in Africa's manufacturing sector. The model includes both the direct effects of key predictors and their interaction terms with industrial emission intensity, thereby capturing the conditional influence of policy-related emission controls on industrial-environmental outcomes. The coefficient for industrial emission intensity (IE) is positive and statistically significant ($\beta = 0.5388$, $t = 13.278$, $p < 0.001$), suggesting that, ceteris paribus, higher industrial emission intensity is associated with increased CO₂ emissions. This finding aligns with Mikayilov et al. (2018) and Amri et al. (2019), who found that emission intensity reflects the level of industrialization and the degree of

reliance on carbon-intensive production processes. The positive relationship underscores that weaker emission controls or energy-inefficient manufacturing practices amplify emissions in Africa's industrial economies.

The manufacturing share of GDP has a positive but statistically insignificant effect ($\beta = 0.0018$, $p = 0.817$). This suggests that variations in manufacturing contribution to GDP, on their own, do not significantly affect CO₂ emissions once other variables and policy effects are controlled for. Similar patterns have been observed in Acheampong (2018) and Aye and Edoja (2017), who found that industrial expansion alone is insufficient to explain emissions differences without accounting for energy structure and technological factors. Energy intensity also exhibits a positive but insignificant relationship with emissions ($\beta = 0.0062$, $p = 0.547$), implying that increases in energy use per unit of GDP do not automatically translate into higher CO₂ emissions. This finding supports evidence from Shahbaz et al. (2019) and Usman and Hammar (2020) that higher energy intensity may coincide with transitions to cleaner fuels or efficiency-enhancing technologies, thereby offsetting potential emissions growth.

The coefficient for scientific and technical journal articles representing scientific innovations and research activity is positive and highly significant ($\beta = 0.0006$, $t = 18.349$, $p < 0.001$). This result suggests that higher research output is associated with greater emissions, at least in the short term. The finding echoes Amri et al. (2019), who observed that early stages of technological advancement in developing economies often lead to higher production and energy consumption before cleaner technologies mature and diffuse widely. The interaction term between manufacturing share of GDP and industrial emission intensity (Manuf. Share of GDP $\times$ IE) is negative and statistically significant ($\beta = -0.0101$, $t = -6.734$, $p < 0.001$). This indicates that the positive relationship between manufacturing activity and CO₂ emissions weakens as industrial emission intensity and by extension, emission regulation increases. In other words, stricter or more effective emission control policies mitigate the emissions impact of industrial growth. This finding is consistent with Adedoyin and Zakari (2020) and Han et al. (2023), who found that policy-driven industrial regulation can help decouple economic growth from emissions in developing regions.

Similarly, the interaction between energy intensity and industrial emission intensity (Energy Intensity $\times$ IE) is negative and significant ($\beta = -0.0214$, $t = -4.543$, $p < 0.001$), suggesting that the emissions effects of energy intensity decline under stronger emission control regimes. This implies that policies targeting industrial energy efficiency such as energy audits, ISO 50001 certification, and energy performance standards are effective in curbing the carbon impact of energy use in the manufacturing sector. These results corroborate the empirical evidence of Usman and Hammar (2020) and Kahia et al. (2019), who demonstrated that policy-induced energy efficiency improvements can reduce emissions intensity across industrial sectors.

Lastly, the interaction between scientific articles and industrial emission intensity (Scientific Articles $\times$ IE) is also negative and highly significant ($\beta = -1.981 \times 10^{-5}$, $t = -19.005$, $p < 0.001$). This finding indicates that while innovation initially correlates with higher emissions, the presence of strong emission control policies reduces this effect. This supports the “green innovation hypothesis” (Mensah et al., 2020; Wenlong et al., 2023), which posits that policy-guided innovation eventually promotes clean technologies that reduce industrial emissions.

Overall, the results show that industrial emission intensity significantly moderates the relationship between industrial dynamics and CO₂ emissions. Stronger emission control policies weaken the positive linkages between manufacturing activity, energy use, innovation, and emissions. This reinforces the view that industrial policy design and environmental regulation are key to achieving low-carbon industrialization in Africa. From a policy perspective, these findings suggest that African countries should not only expand their manufacturing base but also strengthen industrial emission control measures, promote energy efficiency standards, and support innovation in low-carbon technologies. Doing so will ensure that industrial growth and research intensity translate into sustainable and environmentally responsible economic development.

4.8.1 Model Performance and Goodness-of-Fit for the Moderating Model

This subsection evaluates the performance and reliability of the Random Effects Generalized Least Squares (GLS) model used to examine the moderating effect of

industrial emission intensity on the relationship between industrial dynamics and CO₂ emissions in Africa's manufacturing sector. The model's fit was assessed using standard diagnostic statistics, including various R-squared measures, the log-likelihood value, and the F-statistic, to determine how well the explanatory variables jointly account for variations in CO₂ emissions across countries and over time. The results, summarized in Table 4.13, provide an overview of the model's explanatory power, overall fit, and statistical significance, forming the basis for evaluating its suitability for policy interpretation and inference.

Table 4.13: Model Performance and Goodness-of-fit Results

Statistic	Value
R-squared	0.5989
R-squared (Between)	0.8554
R-squared (Within)	0.5145
R-squared (Overall)	0.8169
Log-Likelihood	-583.52
F-statistic	160.42
P-value	0.0000
Distribution	F (7,752)
No. Observations	759

Source (Author, 2025)

The results in Table 4.13 demonstrate that the Random Effects GLS model provides a strong and statistically robust fit for explaining variations in CO₂ emissions across Africa's manufacturing sector. The overall R-squared of 0.8169 indicates that approximately 81.7% of the total variation in CO₂ emissions is jointly explained by the independent variables and their interaction terms. This high explanatory power reflects the model's ability to capture both the structural and dynamic components of emissions, aligning with findings from Amri et al. (2019) and Shahbaz et al. (2019), who similarly reported strong model fits when integrating energy efficiency and innovation variables into environmental models.

The between R-squared value of 0.8554 further suggests that the model explains a substantial proportion of cross-country differences in CO₂ emissions, meaning that structural variations such as differences in industrial energy efficiency policies, technological capabilities and economic structures are key determinants of emissions

disparities across African economies. This is consistent with Acheampong (2018) and Kwakwa et al. (2018), who found that inter-country heterogeneity, particularly in energy consumption and industrial policy regimes, accounts for a significant share of emissions variance on the continent. Conversely, the within R-squared of 0.5145 indicates that approximately 51% of the variation in CO₂ emissions within countries over time is explained by the included predictors. This finding emphasizes that while time-varying industrial dynamics such as shifts in energy intensity, manufacturing output, and innovation play a meaningful role, unobserved time-specific shocks (e.g., policy reforms, energy price fluctuations or technological breakthroughs) may also influence emissions outcomes. This is consistent with Mensah et al. (2018) and Han et al. (2023), who argue that temporal changes in industrial energy efficiency and innovation adoption often produce lagged or nonlinear impacts on emissions.

The F-statistic of 160.42 with a p-value of 0.0000 confirms that the model is highly statistically significant, meaning the explanatory variables collectively have strong predictive power for CO₂ emissions. This aligns with empirical evidence from Adedoyin and Zakari (2020) and Mikayilov et al. (2018), who similarly demonstrated that including policy and energy-efficiency interactions in regression models substantially enhances explanatory power and overall model significance in emissions-related studies. The log-likelihood value of -583.52 reflects the model's overall goodness-of-fit, with higher (less negative) values indicating superior model adequacy relative to competing specifications. The relatively high log-likelihood observed here suggests that the model fits the data well, particularly after incorporating interaction effects that capture the moderating influence of industrial emission intensity policies. This reinforces the theoretical proposition advanced by Usman and Hammar (2020) that energy and emission policy variables substantially improve model precision in environmental econometrics.

The observed model performance corroborates prior empirical findings that integrated approaches combining industrial, technological, and policy dimensions offer a more comprehensive explanation of emissions behavior in developing regions. Studies such as Amri et al. (2019) in Tunisia and Mikayilov et al. (2018) in Azerbaijan found that including emission efficiency measures significantly improved model explanatory power.

Similarly, Acheampong (2018) demonstrated that energy consumption and technological progress jointly explain a substantial proportion of CO₂ variation when examined under robust econometric frameworks.

4.9 Chapter Summary

Chapter Four analyzed data from forty-seven African countries (2000–2022) to examine the effect of industrial dynamics on CO₂ emissions and the moderating role of industrial emission intensity policies. Descriptive analysis revealed substantial cross-country disparities, with emissions concentrated in a few industrialized economies. Correlation results showed strong positive relationships between CO₂ emissions, manufacturing value added, and emission intensity, while innovation was linked to higher emissions, reflecting production-oriented research. Diagnostic tests confirmed heteroskedasticity and autocorrelation but validated stationarity, justifying the use of the Random Effects Generalized Least Squares (GLS) model. Regression results indicated that energy intensity and manufacturing share of GDP reduce emissions, whereas innovation increases them. Incorporating industrial emission intensity as a moderating variable improved model fit and revealed significant moderating effects, weakening the positive link between industrial growth and emissions. Overall, the findings highlight the critical role of industrial emission policies and energy efficiency measures in achieving sustainable, low-carbon industrialization in Africa.

Chapter 5: Discussion, Conclusion and Recommendation

5.1 Introduction

This chapter integrates and interprets the study's findings on the effect of industrial dynamics on CO₂ emissions in Africa's manufacturing sector. It aims to link empirical results with theory and policy implications. The chapter presents the summary of findings, discussion, conclusion, recommendations, study limitations, and future research directions, offering insights into how industrialization, innovation, and emission policies interact to promote sustainable, low-carbon growth across African economies.

5.2 Summary of Findings

This study set out to examine the effect of industrial dynamics (energy intensity, manufacturing share of GDP and scientific innovations) on carbon dioxide (CO₂) emissions in Africa's manufacturing sector, as well as the moderating role of industrial emission intensity as a proxy for emissions policies. Using panel data from forty-seven (47) African countries over the period 2000–2022, the study employed a Random Effects Generalized Least Squares (GLS) model to account for heteroskedasticity, serial correlation and unobserved country-specific heterogeneity. The discussion below interprets the key findings of the study.

5.2.1 Descriptive Statistics

The descriptive profile reveals marked cross-country heterogeneity over 2000–2022. CO₂ emissions are heavily right-skewed (skewness ≈ 3.85 ; kurtosis ≈ 17.39), with a few industrial hubs; South Africa, Egypt, Nigeria, and Algeria dominating the continental footprint, while the majority of countries emit relatively little. Mean energy intensity stands at 6.36 MJ per \$2017 PPP GDP (SD ≈ 3.90 ; skewness ≈ 1.64), indicating widespread inefficiency and a long upper tail of very high energy users (e.g., Mozambique, Zimbabwe, Ethiopia, Liberia). Manufacturing's average share of GDP is modest at 1.09% (SD ≈ 5.90) but highly dispersed, signaling structural differences in industrialization that map onto emissions disparities. Industrial emissions intensity is also extreme and heavy-tailed (skewness ≈ 6.11 ; kurtosis ≈ 38.32), confirming that a small set of economies rely on carbon-intensive energy mixes. Innovation capacity proxied by

scientific and technical journal articles shows stark concentration in a handful of research-active countries, reinforcing unequal readiness to absorb clean technologies. Collectively, these patterns corroborate empirical findings that structural inefficiencies and energy mix choices rather than scale alone drive Africa's emissions heterogeneity (Acheampong, 2018; Mikayilov et al., 2018), and they underscore the need for diffusion of green technologies and energy-efficiency upgrades beyond current innovation hubs.

5.2.2 Correlation Analysis

The correlation analysis revealed strong and statistically meaningful associations between CO₂ emissions and key indicators of industrial dynamics. Specifically, CO₂ emissions showed a robust positive correlation with manufacturing value added ($r = 0.66$), industrial emission intensity ($r = 0.59$), and scientific and technical journal publications ($r = 0.73$). These results suggest that higher industrial output and intensified innovation activity are accompanied by increased emissions, highlighting the carbon-intensive nature of Africa's manufacturing growth trajectory. This pattern mirrors findings by Kwakwa et al. (2018) and Mensah et al. (2020), who noted that industrial expansion and production-driven R&D tend to elevate emissions in the early stages of industrial transformation before cleaner technologies are fully adopted. Interestingly, energy intensity displayed a weak but negative correlation with CO₂ emissions ($r = -0.21$), implying that higher energy use per unit of GDP does not necessarily translate to higher emissions. This counterintuitive relationship suggests that some countries may be improving energy efficiency or transitioning toward lower-carbon energy sources, such as hydropower or natural gas, in line with findings by Amri et al. (2019) and Shahbaz et al. (2019).

5.2.3 Diagnostic Tests

A comprehensive suite of diagnostic tests was conducted to ensure the robustness, validity, and econometric soundness of the estimated models. The Variance Inflation Factor (VIF) analysis confirmed the absence of serious multicollinearity among the explanatory variables after the exclusion of manufacturing value added, with all remaining VIF values falling below the critical threshold of 5. This indicates that the independent variables are sufficiently distinct in capturing different aspects of industrial dynamics, ensuring stable and reliable coefficient estimates.

The Breusch–Pagan test revealed statistically significant heteroskedasticity ($p < 0.001$), indicating that the variance of the residuals is not constant across observations—a common feature in multi-country environmental and economic datasets. Similarly, the Ljung–Box Q-test confirmed strong autocorrelation across variables ($p < 0.001$), suggesting serial dependence typical of macro-panel data where industrial and environmental indicators evolve gradually over time. These findings are consistent with earlier empirical studies by Acheampong (2018) and Amri et al. (2019), who observed similar data characteristics in studies on energy use and emissions across developing economies.

The Augmented Dickey–Fuller (ADF) test results established that all variables were stationary at level, thereby eliminating the risk of spurious regression and validating the use of time-series and panel estimators. The Anderson–Darling (AD) normality test indicated non-normal residual distributions, a feature expected in heterogeneous cross-country data with large disparities in industrialization and emissions. Consequently, the adoption of the Generalized Least Squares (GLS) estimator was justified, as it provides efficient, consistent, and unbiased estimates under heteroskedastic and autocorrelated conditions. Finally, the Hausman specification test ($p = 1.000$) confirmed the appropriateness of the Random Effects Model, implying that unobserved country-specific effects are uncorrelated with the regressors. This aligns with prior cross-country environmental modeling by Mikayilov et al. (2018), supporting the efficiency and generalizability of the Random Effects–GLS specification for analyzing the relationship between industrial dynamics and CO₂ emissions across African economies.

5.2.4 Direct Effects of Industrial Dynamics on CO₂ Emissions

The Random Effects Generalized Least Squares (GLS) estimation results reveal significant heterogeneity in the determinants of CO₂ emissions within Africa's manufacturing sector. The findings indicate that energy intensity exerts a negative and highly significant effect on CO₂ emissions ($\beta = -0.0627$, $p < 0.001$), suggesting that improvements in energy efficiency or shifts toward less carbon-intensive energy sources contribute to emission reductions. This supports the argument advanced by Acheampong

(2018) and Mikayilov et al. (2018) that structural changes and efficiency gains can lead to a partial decoupling of economic growth from emissions.

Similarly, the manufacturing share of GDP displays a negative and statistically significant relationship with emissions ($\beta = -0.0322$, $p < 0.05$), implying that economies with a more robust and diversified manufacturing base may achieve lower emission intensities through technology upgrading, economies of scale, and greater energy efficiency. This outcome aligns with the findings of Shahzad et al. (2020) and Kahia et al. (2019), who observed that industrial transformation can support sustainable production when accompanied by cleaner technologies and energy management systems. Conversely, scientific and technical publications exhibit a positive and highly significant effect ($\beta = 0.00034$, $p < 0.001$), indicating that, in the short term, increased innovation and research output are associated with higher emissions. This relationship likely reflects production-driven innovation, where technological advancements initially enhance industrial activity and energy use before transitioning toward cleaner processes a dynamic consistent with the Environmental Kuznets Curve (EKC) framework and findings by Mensah et al. (2018) and Du et al. (2019).

The model explains 39% of the overall variation in CO₂ emissions ($R^2 = 0.3901$), demonstrating a moderate yet meaningful explanatory power typical of multi-country panel analyses in environmental economics. This level of fit is comparable to the results of Acheampong (2018) and Shahzad et al. (2020), reaffirming that industrial structure, energy efficiency, and innovation collectively capture the key drivers of emission dynamics in African manufacturing. The results underscore the need for targeted policies that simultaneously enhance energy efficiency, encourage green innovation, and promote structural diversification to achieve low-carbon industrial development.

5.2.5 Moderating Role of Industrial Emission Intensity

The introduction of industrial emission intensity as a moderating variable substantially enhanced the explanatory power and overall fit of the model, with the overall R^2 increasing to 0.8169 and the F-statistic ($F = 160.42$, $p < 0.001$) confirming strong joint significance of the predictors. This marked improvement demonstrates that accounting

for emission control dynamics significantly strengthens the model's capacity to explain variations in CO₂ emissions across African manufacturing economies. The results indicate that industrial emission intensity exerts a positive and highly significant direct effect on CO₂ emissions ($\beta = 0.5388$, $p < 0.001$), implying that countries with higher emission intensities often indicative of weaker regulatory frameworks, limited adoption of clean technologies, or reliance on carbon-intensive energy sources experience elevated levels of industrial emissions. This finding corroborates evidence by Mikayilov et al. (2018) and Amri et al. (2019), who similarly observed that lax environmental regulations and inefficient energy structures amplify emissions in emerging industrial economies.

However, the interaction terms between industrial emission intensity and the key industrial dynamics manufacturing share of GDP ($\beta = -0.0101$, $p < 0.001$), energy intensity ($\beta = -0.0214$, $p < 0.001$), and scientific innovations ($\beta = -1.981 \times 10^{-5}$, $p < 0.001$) are all negative and statistically significant. These results suggest that stronger industrial emission policies mitigate the positive linkages between industrial activity, energy use, innovation, and CO₂ emissions. Specifically, as the effectiveness of emission control frameworks improves, the marginal impact of manufacturing expansion, energy consumption, and technological development on emissions diminishes. This moderating effect underscores the critical role of policy interventions in aligning industrialization with sustainability objectives. It demonstrates that well-designed emission control mechanisms, including industrial energy efficiency programs, mandatory reporting standards, and incentives for low-carbon innovation, can decouple economic growth from carbon emissions. These findings are consistent with the empirical evidence reported by Adedoyin and Zakari (2020) and Han et al. (2023), who found that environmental policy enforcement significantly weakens the emissions-growth nexus in developing economies.

5.3 Discussion

The purpose of this study was to investigate the effect of industrial dynamics on carbon dioxide (CO₂) emissions in Africa's manufacturing sector, and to determine how industrial emission intensity moderates these relationships. The discussion below integrates the empirical findings presented in Chapter Four with theoretical expectations

and the broader empirical literature, offering a deeper interpretation of the results within the context of sustainable industrialization and environmental policy in Africa.

5.3.1 Industrial Structure, Energy Efficiency and Emissions Patterns

The descriptive and correlation analyses confirm that Africa's CO₂ emissions are highly concentrated in a few industrialized economies; South Africa, Egypt, Nigeria, and Algeria reflecting unequal industrial capacities and heterogeneous energy structures across the continent. This finding aligns with Acheampong (2018) and Mikayilov et al. (2018), who documented that structural inefficiency and dependence on fossil-fuel-based manufacturing drive emission disparities in developing regions. The concentration of emissions in a few countries supports the Environmental Kuznets Curve (EKC) hypothesis in its early stages, where industrial expansion initially raises emissions before the benefits of technological progress and regulatory maturity are realized.

The results further highlight that average energy intensity across Africa (6.36 MJ per \$2017 PPP GDP) remains considerably high, implying that industrial production is still energy-inefficient relative to global standards. The persistence of high energy intensity despite limited industrial output underscores the inefficiency of energy conversion technologies and the limited penetration of clean energy sources. These findings reinforce the arguments by Kwakwa et al. (2018) and Amri et al. (2019), who observed that energy inefficiency is a structural barrier to sustainable industrialization in Africa. However, the weak negative correlation between energy intensity and CO₂ emissions ($r = -0.21$) may reflect gradual energy diversification, particularly through hydropower expansion in countries such as Ethiopia, Kenya, and Zambia, consistent with the energy transition pathways highlighted by Shahbaz et al. (2019).

5.3.2 Industrial Dynamics and the CO₂ Growth Nexus

The Random Effects Generalized Least Squares (GLS) estimates revealed nuanced relationships between industrial dynamics and CO₂ emissions. The negative and statistically significant effect of energy intensity ($\beta = -0.0627$, $p < 0.001$) suggests that improvements in energy efficiency or shifts toward cleaner energy sources contribute to emission reductions. This result corroborates Acheampong (2018), who found that

reductions in energy intensity helped decouple growth from emissions in South Africa, and Mikayilov et al. (2018), who reported similar findings for Azerbaijan. Thus, within the African context, improved energy management and modernization of industrial processes appear to yield tangible emission benefits.

The manufacturing share of GDP also displayed a negative and significant effect ($\beta = -0.0322$, $p < 0.05$), implying that manufacturing expansion does not necessarily exacerbate emissions when accompanied by structural upgrading and scientific innovations. This observation resonates with Shahzad et al. (2020), who found that industrial growth linked to productivity improvements and technology diffusion can support carbon-efficient development. The result further suggests that countries transitioning from extractive to manufacturing-led growth may experience lower carbon intensity per unit of output, consistent with the “clean industrialization” hypothesis.

In contrast, scientific and technical publications a proxy for scientific innovations had a positive and highly significant association with emissions ($\beta = 0.00034$, $p < 0.001$). This indicates that innovation in African manufacturing currently operates within a production-expanding paradigm rather than a clean-technology-oriented one. As Mensah et al. (2018) and Du et al. (2019) argue, early-stage innovation in developing economies often increases emissions in the short run due to technology commercialization, industrial scaling, and higher energy use, with emission reductions emerging only after diffusion of green innovations. This finding reinforces the need for aligning research and development agendas with low-carbon technology adoption and diffusion.

5.3.3 Moderating Role of Industrial Emission Intensity Policies

Incorporating industrial emission intensity as a moderating variable substantially improved the model’s explanatory power ($R^2 = 0.8169$), demonstrating that emission policy mechanisms are a crucial determinant of the CO₂–industrialization relationship. The positive direct effect of industrial emission intensity ($\beta = 0.5388$, $p < 0.001$) underscores that countries with weak environmental regulation, inefficient energy systems, and high reliance on fossil fuels exhibit significantly higher emissions. This aligns with Amri et al. (2019) and Mikayilov et al. (2018), who emphasized that

institutional and policy quality profoundly shape environmental outcomes in developing regions.

More importantly, the negative and statistically significant interaction terms between industrial emission intensity and key industrial dynamics manufacturing share of GDP ($\beta = -0.0101$, $p < 0.001$), energy intensity ($\beta = -0.0214$, $p < 0.001$), and scientific innovations ($\beta = -1.981 \times 10^{-5}$, $p < 0.001$) demonstrate that effective emission policies can substantially weaken the positive linkages between industrial activity, energy use, innovation, and emissions. These findings corroborate Adedoyin and Zakari (2020) and Han et al. (2023), who found that stringent industrial energy-efficiency standards and regulatory enforcement moderate the emissions-growth nexus in developing economies.

5.3.4 Implications for Sustainable Industrialization in Africa

The results of this study offer important implications for the continent's sustainable industrial development agenda. First, while industrialization remains central to Africa's economic transformation, the findings demonstrate that without targeted policy frameworks, the manufacturing sector risks entrenching carbon-intensive growth patterns. Second, the significant moderating role of industrial emission intensity underscores that policy coherence linking industrial, energy, and environmental strategies is essential for achieving decarbonization targets. Third, the observed positive short-term relationship between innovation and emissions suggests that African economies must reorient their innovation systems toward green R&D, renewable energy integration, and industrial process optimization to transition effectively to low-carbon manufacturing.

5.4 Conclusion

This study set out to investigate the effect of key industrial dynamics; energy intensity, manufacturing share of GDP and scientific innovations on carbon dioxide (CO₂) emissions in Africa's manufacturing sector, while also examining the moderating influence of industrial emission intensity as a proxy for the strength of emissions policies. Using panel data from forty-seven African countries spanning 2000–2022, and employing a Random Effects Generalized Least Squares (GLS) estimation technique, the study provides robust

empirical insights into how structural, technological, and policy factors jointly shape the continent's emissions trajectory.

The findings reveal that energy intensity and manufacturing share of GDP are both negatively and significantly associated with CO₂ emissions, suggesting that efficiency improvements and structural transformation play a critical role in emissions mitigation. These results imply that as African economies diversify their industrial base and improve production efficiency, they are gradually decoupling economic growth from environmental degradation. This provides empirical validation for the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted-U relationship between economic growth and environmental degradation where emissions initially rise during early industrialization but decline as economies mature and adopt cleaner technologies. The evidence from this study indicates that many African economies are approaching the turning point of the EKC, transitioning from emission-intensive growth toward more sustainable, efficiency-driven industrialization.

Conversely, the positive and significant relationship between scientific innovations (proxied by scientific and technical publications) and CO₂ emissions highlights a short-term trade-off between technological advancement and environmental sustainability. This finding suggests that current innovation systems across Africa remain largely production-oriented, prioritizing industrial expansion and output growth over environmental performance. This pattern aligns with the early stages of the EKC and supports prior evidence by Mensah et al. (2018) and Du et al. (2019) that innovation may initially increase emissions before contributing to green transformation once clean technologies diffuse widely. The implication is that policy realignment is necessary to direct research and development efforts toward low-carbon innovation, renewable energy integration, and eco-efficient manufacturing processes.

A central contribution of this study lies in incorporating industrial emission intensity as a moderating variable, capturing the influence of policy-driven emission control mechanisms. The integration of this variable significantly enhanced model performance (R^2 overall = 0.8169), underscoring the importance of regulatory and institutional quality

in shaping environmental outcomes. The positive direct effect of emission intensity on CO₂ emissions confirms that weak or poorly enforced emission policies exacerbate environmental degradation, while the negative and statistically significant interaction effects demonstrate that stronger emission control frameworks attenuate the impact of industrial activity, energy use, and innovation on emissions. These findings provide empirical support for the “strong version” of the Porter Hypothesis, which argues that well-designed environmental regulations can stimulate efficiency, foster scientific innovations, and ultimately improve both economic and environmental performance.

In contrast, the results challenge the validity of the Resource Curse Theory within the African industrial context. The negative association between manufacturing share of GDP and emissions implies that industrial diversification particularly into manufacturing can reduce carbon intensity, contrary to the resource curse narrative, which predicts that resource-dependent economies suffer from inefficiency, weak governance, and environmental degradation. Instead, the evidence suggests that African economies moving away from primary resource dependence toward manufacturing-led growth may be escaping the resource curse, provided that industrialization is guided by energy-efficient and environmentally responsible policies.

5.5 Recommendations

The findings of this study have important implications for policy, practice and academia, particularly as Africa seeks to achieve sustainable industrialization while curbing carbon emissions. The results revealed that energy intensity and manufacturing share of GDP are negatively related to CO₂ emissions, while innovation currently contributes to higher emissions in the short run. Moreover, the moderating effect of industrial emission intensity demonstrated that robust environmental policies significantly weaken the positive relationship between industrial dynamics and emissions. These insights call for coordinated strategies that integrate energy efficiency, regulatory reform, scientific innovations, and regional cooperation into Africa’s industrial development agenda.

From a policy perspective, governments across Africa should prioritize the strengthening of industrial energy efficiency frameworks as a foundation for low-carbon growth. Since

the study established that reductions in energy intensity significantly lower CO₂ emissions, policies must focus on incentivizing firms to adopt energy-efficient technologies and modernize production systems. Governments can achieve this through fiscal and financial mechanisms such as tax rebates, concessional green financing, and subsidies for industries that invest in clean production technologies. Furthermore, national energy agencies should enforce mandatory energy audits and develop clear performance benchmarks for industrial subsectors to ensure measurable progress. Such measures would not only reduce carbon emissions but also enhance the competitiveness of African industries in global markets increasingly governed by sustainability standards.

Equally critical is the integration of emission standards into national and regional industrial policies. The study's findings that industrial emission intensity strongly influences CO₂ emissions emphasize the need for mandatory emissions reporting, continuous monitoring, and sectoral benchmarking. Establishing national emission registries linked to a continental emissions database coordinated by regional bodies such as the African Union (AU) or the African Development Bank (AfDB) would enhance transparency and accountability. Furthermore, governments should introduce carbon pricing or cap-and-trade mechanisms to internalize environmental costs, thereby encouraging industries to transition to cleaner production practices. By embedding emission standards within industrial policy frameworks, African countries can align economic transformation with their commitments under the Paris Agreement and Sustainable Development Goals (SDGs).

Another critical policy direction involves aligning innovation and technological progress with decarbonization goals. Although this study found that scientific and technical innovation currently correlates with higher emissions, this outcome reflects the dominance of production-oriented rather than green innovation. To reverse this trend, governments should redirect national innovation systems toward supporting low-carbon technological research and commercialization. Strengthening partnerships among universities, research institutions, and industries is essential to foster the diffusion of green technologies and facilitate the development of local capacity for sustainable industrial processes. Creating innovation funds, research grants, and technology

incubators dedicated to clean energy and sustainable manufacturing will ensure that innovation becomes a driver of both economic growth and emissions reduction.

A related but equally important policy recommendation is the diversification of Africa's energy mix. The findings underscore that reliance on carbon-intensive fuels remains a major barrier to emission reduction. Therefore, governments should invest heavily in renewable energy infrastructure including solar, wind, hydro, and geothermal power to support manufacturing activities with cleaner and more reliable energy sources. Public-private partnerships and regional power-pooling initiatives can mobilize financing for large-scale renewable projects while simultaneously enhancing energy security. This transition toward renewables would also foster local manufacturing of renewable energy technologies, creating green jobs and expanding industrial capacity.

Regional cooperation is another cornerstone of effective emissions management. Since industrial emissions transcend national borders, collective action at the regional level is crucial. Institutions such as the AU, the Regional Economic Communities (RECs), and UNECA should work collaboratively to harmonize emission standards, facilitate cross-border technology transfer, and coordinate joint investments in green industrial infrastructure. Establishing regional centers of excellence for industrial decarbonization would promote knowledge exchange and foster capacity building in emissions monitoring, clean production, and energy efficiency. Such collaboration would accelerate the continent's progress toward a harmonized low-carbon industrial framework, ensuring that Africa speaks with one voice in global climate negotiations.

At the level of industrial practice, firms must take a proactive role in decarbonizing production. The study's findings indicate that industrial efficiency gains can substantially reduce emissions, and firms should therefore adopt cleaner production principles and circular economy models. These include optimizing resource use, minimizing waste, recycling industrial by-products, and investing in modern, energy-efficient technologies. The adoption of international standards such as ISO 14001 (Environmental Management Systems) and ISO 50001 (Energy Management Systems) would institutionalize environmental accountability and provide firms with structured pathways to reduce their

carbon footprints. Moreover, firms should build technical and managerial capacity to implement energy audits, monitor emissions, and comply with emerging regulatory frameworks. By embedding environmental governance into their operational culture, manufacturing enterprises can improve both sustainability and profitability.

From an academic standpoint, the study opens several avenues for future research. First, scholars should expand the analytical scope to include sector-specific and firm-level analyses of emissions to capture heterogeneity within manufacturing subsectors such as cement, textiles, and chemicals. Second, future research should explore the nonlinear and dynamic relationships between industrialization, innovation, and emissions using advanced econometric techniques such as dynamic panel models or threshold regression. This would deepen understanding of the turning points in the Environmental Kuznets Curve within the African context. Third, comparative policy studies assessing the effectiveness of industrial emission regulations across countries could provide valuable insights into the institutional determinants of policy success. Finally, researchers should investigate the role of green finance, technology transfer, and international cooperation in facilitating Africa's industrial decarbonization, especially in the context of emerging carbon markets and sustainable finance mechanisms.

5.6 Limitations of the Study

While this study offers valuable empirical insights into the relationship between industrial dynamics and carbon dioxide (CO₂) emissions in Africa's manufacturing sector, several limitations should be acknowledged. These limitations do not undermine the validity of the findings but rather delineate the scope of inference and identify potential areas for future refinement. First, the analysis relied exclusively on secondary data obtained from international databases such as the World Bank, UNIDO, and Climate Watch. Although these sources are widely recognized for their reliability and comparability, they are not immune to measurement errors, reporting inconsistencies, and temporal lags in data updates. Variations in national reporting standards and data quality may have introduced minor inaccuracies that could affect cross-country comparability, particularly for nations with weaker statistical capacities or incomplete historical records.

Second, the study employed industrial emission intensity as a proxy indicator for the strength of emission control policies. While this measure provides a useful approximation of policy effectiveness, it may not fully capture the qualitative dimensions of environmental governance, such as enforcement rigor, institutional capacity, and political commitment to emission regulation. As a result, the moderating effect observed in the model reflects the aggregate outcome of emission policies rather than their direct implementation or compliance characteristics. Third, the econometric model did not explicitly incorporate variables representing institutional quality, governance effectiveness, or regulatory strictness, which are known to influence both industrial performance and environmental outcomes. The exclusion of these governance-related variables was primarily due to data limitations and concerns about multicollinearity. However, their omission may have resulted in omitted variable bias, limiting the ability to disentangle the effects of industrial structure from those of institutional context.

Fourth, although the panel data design enhances statistical efficiency and allows for the control of unobserved heterogeneity across countries and over time, the estimated relationships should be interpreted as associative rather than strictly causal. The study did not employ instrumental variable techniques, structural equation modeling, or quasi-experimental designs that could establish causal directionality between industrial dynamics and emissions outcomes. Consequently, while the findings demonstrate statistically robust associations, causality remains inferential rather than definitive. Lastly, the study adopted a macro-level, cross-country analytical approach, which, while valuable for identifying continental trends, may mask important sectoral or firm-level variations within individual economies. Manufacturing subsectors such as cement, textiles, and food processing may exhibit distinct energy-use patterns and emissions profiles that are not fully captured in aggregate national data. This limits the granularity of insights that could inform more targeted industrial and environmental policy interventions.

5.7 Recommendations for Further Studies

Building upon the limitations identified in this study, several areas warrant further scholarly investigation to deepen understanding of the relationship between industrial

dynamics, policy frameworks, and carbon emissions in Africa's manufacturing sector. First, given the reliance on secondary data from international databases, future research should consider incorporating primary data collection or triangulating multiple data sources to enhance the accuracy and reliability of country-level indicators. Survey-based or firm-level data could provide richer insights into actual energy use patterns, technological adoption, and policy compliance within manufacturing enterprises. Such micro-level data would help overcome potential measurement errors and reporting inconsistencies inherent in secondary datasets.

Second, this study utilized industrial emission intensity as a proxy for the presence and strength of emission control policies. Although this quantitative measure offered a useful approximation, it did not fully capture the qualitative dimensions of institutional enforcement, regulatory quality, or policy effectiveness. Future studies should therefore integrate institutional quality indices, environmental governance indicators, and policy enforcement metrics such as those available from the Worldwide Governance Indicators (WGI) or Climate Policy Initiative to better understand how governance capacity moderates the emissions-industrialization nexus. Third, the omission of explicit governance and institutional variables presents an opportunity for future studies to examine how institutional frameworks interact with industrial dynamics to shape emission trajectories. Incorporating variables such as rule of law, regulatory control, and political stability into the empirical framework could reveal whether countries with stronger governance structures achieve more efficient decoupling of industrial growth from emissions. Comparative analyses between high- and low-governance contexts would provide valuable insights into the institutional preconditions for successful emission mitigation.

Fourth, the study's reliance on a Random Effects Generalized Least Squares (GLS) model, while robust for addressing heteroskedasticity and serial correlation, limits causal interpretation. To establish stronger causal relationships, future research should employ advanced econometric identification strategies, such as instrumental variable (IV) estimation, difference-in-differences (DiD) models, or natural experiments that exploit exogenous policy shocks or international environmental agreements. These approaches

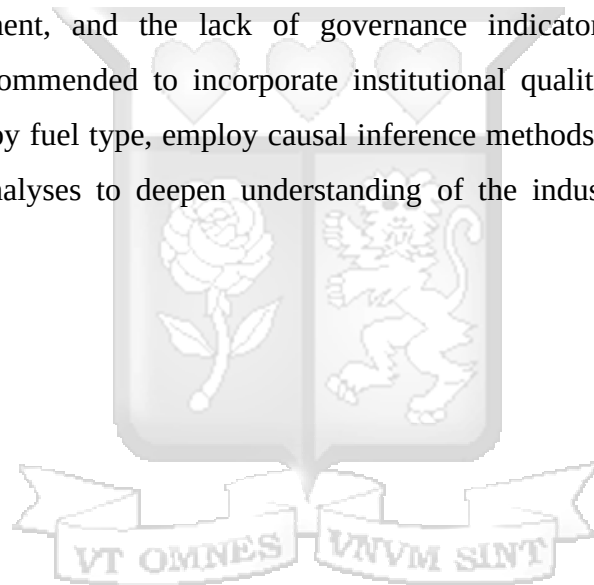
would help isolate the direction of causality between industrial activity, policy enforcement, and emission outcomes, thereby strengthening empirical validity. Fifth, although the current study adopts a macro-level, cross-country analytical approach, the aggregated nature of the data may mask sectoral or firm-level variations. Future studies could therefore conduct country-specific or industry-level case studies to capture the heterogeneity within Africa's manufacturing landscape. Subsector analyses for example, focusing on energy-intensive industries such as cement, steel, and textiles would reveal distinct emission drivers and policy responses, facilitating more targeted and context-sensitive interventions.

Additionally, further research could explore nonlinear or threshold relationships between industrial growth and emissions using dynamic or nonlinear panel techniques. Employing models such as panel threshold regressions, Generalized Method of Moments (GMM), or Smooth Transition Regression (STR) could uncover whether the emissions–growth relationship changes as economies reach higher levels of industrialization or technological capability. This would contribute to refining the Environmental Kuznets Curve (EKC) hypothesis within the African context. Lastly, given the continent's growing emphasis on renewable energy and sustainable manufacturing, future work should disaggregate energy intensity by fuel type to assess the differential impacts of renewable and fossil-based energy sources on CO₂ emissions. Such analysis would provide actionable evidence for policy design, particularly in identifying which energy transitions yield the greatest environmental benefits without compromising industrial productivity.

5.8 Chapter Summary

Chapter Five presented the synthesis, interpretation, and implications of the study's findings on the relationship between industrial dynamics and CO₂ emissions in Africa's manufacturing sector. The discussion established that energy intensity and manufacturing share of GDP are negatively and significantly associated with emissions, demonstrating that efficiency improvements and structural transformation are key pathways to emission reduction. In contrast, scientific innovations was found to increase emissions in the short term, emphasizing the need to reorient research and development toward green

technologies and sustainable industrial practices. The inclusion of industrial emission intensity as a moderating variable significantly enhanced model performance, revealing that stronger emission policies weaken the positive relationship between industrial activity, energy use, innovation, and CO₂ emissions. These results highlight the pivotal role of policy-driven interventions and regulatory frameworks in promoting low-carbon industrialization across Africa. The chapter further provided policy, practical, and academic recommendations, including the need to strengthen industrial energy efficiency programs, integrate stricter emission standards, promote green innovation, diversify the energy mix, and enhance regional collaboration on industrial decarbonization. The limitations acknowledged challenges such as reliance on secondary data, proxy-based policy measurement, and the lack of governance indicators. Consequently, future research was recommended to incorporate institutional quality variables, disaggregate energy intensity by fuel type, employ causal inference methods, and conduct country- or sector-specific analyses to deepen understanding of the industrial–emissions nexus in Africa.



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Appendix I: Similarity Report

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Appendix II: Ethical Approval Letter



24th October 2025

Dr Gathuru Edmund,
edmund.gathuru@strathmore.edu

Dear Dr Gathuru,

RE: Effect of Industrial Dynamics on Carbon Dioxide Emissions in Africa's Manufacturing Sector and the Moderating Role of Industrial Emissions Policies

This is to inform you that SU-ISERC has reviewed and **approved** your above **SU-masters** research proposal. Your application reference number is **SU-ISERC3057/25**. The approval period is from **24th October 2025 to 23rd October 2026**.

This approval is subject to compliance with the following requirements:

- i. Only approved documents including (informed consents, study instruments, and MTA) will be used
- ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by SU-ISERC.
- iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to SU-ISERC within 72 hours of notification
- iv. Any changes, anticipated or otherwise, that may increase the risks or affect the safety or welfare of study participants and others or affect the integrity of the research must be reported to SU-ISERC within 72 hours
- v. Clearance for the export of biological specimens must be obtained from relevant institutions.
- vi. Submission of a request for renewal of approval at least 60 days prior to the expiry of the approval period. Attach a comprehensive progress report to support the renewal.
- vii. Submission of an executive summary report within 90 days of completion of the study to SU-ISERC.

Before commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology, and Innovation (NACOSTI) <https://research-portal.nacosti.go.ke/> and obtain other clearances needed.

Yours sincerely,

A handwritten signature in black ink, appearing to read "Ambrose Rachier".

Mr Ambrose Rachier,
Chairperson; SU-ISERC

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Appendix III: Introductory Letter from the University

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27th October 2025

Director General,
National Commission for Science Technology and Innovation,
P.O. Box 30623, 00100
Nairobi.

Dear Sir/Madam,

RE: FACILITATION OF RESEARCH – GATHURU EDMOND

This is to introduce Gathuru Edmund Kanyugi, who is a Master of Science in Development Finance (MDF) Student at Strathmore University Business School, admission number MDF/48990/23. As part of our MDF Program, Edmond is expected to do applied research and undertake a project. This is in partial fulfillment of the requirements of the MDF course.

Edmond is undertaking a research paper on **"Effect of Industrial Dynamics on Carbon Dioxide Emissions in Africa's Manufacturing Sector and the Moderating Role of Industrial Emissions Policies."** The information obtained shall be treated confidentially and shall be used for academic purposes only.

Our MDF seeks to establish links with industry, and one of these ways is by directing our research to areas that would be of direct use to industry. We would be glad to share our findings with you after the research.

We appreciate your support and shall be willing to provide any further information if required.

Yours sincerely,

Njoki Kiagiri
Manager - Graduate Programmes.

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