

CO₂ Emission Drivers: The Impact of Energy Consumption, Green Finance, Institutional Quality, and Research and Development



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ABSTRACT

The relentless rise in global carbon dioxide (CO₂) emissions presents a formidable challenge to climate stability and sustainable development. This study provides a comprehensive, integrated assessment of the key drivers of CO₂ emissions, moving beyond isolated analyses to examine the simultaneous impact of energy consumption patterns, financial mechanisms, institutional frameworks, and innovation capacity. Utilizing a balanced panel dataset spanning the years 2000 to 2024 for ten major and emerging economies (Argentina, Brazil, China, India, Indonesia, Mexico, Russia, Saudi Arabia, South Africa, and Turkiye), the research employs fixed effects regression models to test a series of hypotheses derived from the Environmental Kuznets Curve (EKC) and related theoretical literature.

The empirical findings robustly confirm that renewable energy consumption and research & development (R&D) expenditure significantly reduce CO₂ emissions. Conversely, fossil fuel energy consumption and GDP growth exhibit strong positive effects, underscoring their roles as primary emission drivers. The study also identifies green finance (proxied by financial development) and institutional quality as significant negative determinants, highlighting the critical enabling roles of sustainable financial systems and effective governance in the decarbonization process. Among the control variables, population growth shows a positive association with emissions, while the effects of GDP per capita growth and foreign direct investment (FDI) are statistically ambiguous in the selected sample.

The results offer significant theoretical contributions by integrating multiple drivers into a unified framework and advancing the EKC discourse. Practically, the study provides evidence-based policy implications, emphasizing the need for accelerated renewable energy deployment, fossil fuel subsidy reforms, enhanced green R&D investment, strengthened environmental governance, and the scaling up of green finance instruments to achieve sustainable, low-carbon economic growth.

Keywords: CO₂ Emissions, Renewable Energy, Fossil Fuels, Green Finance, Institutional Quality, Research & Development (R&D), Environmental Kuznets Curve (EKC), Panel Data Analysis, Sustainable Development, Climate Policy, etc.

Table of Contents

APPROVAL SHEET	Error! Bookmark not defined.
THESIS COMPLETION CERTIFICATE.....	Error! Bookmark not defined.
DECLARATION OF AUTHENTICATION.....	Error! Bookmark not defined.
PILGRIMS UNDERTAKING.....	Error! Bookmark not defined.
ACKNOWLEDGEMENT.....	ii
ABSTRACT	iii
Chapter 1.....	1
INTRODUCTION	1
1.1 Background of the Study	1
1.2 Research Gap	3
1.3 Problem Statement.....	3
1.4 Research Rationale	4
1.5 Research Aim.....	4
1.6 Research Objectives.....	5
1.7 Research Questions.....	5
1.8 Research Significance.....	5
<i>1.8.1 Theoretical Significance</i>	<i>5</i>
<i>1.8.2 Practical Significance.....</i>	<i>6</i>
1.9 Thesis Structure	6
1.10 Chapter Summary	6
Chapter 2.....	7
LITERATURE REVIEW	7
2.0 Introduction.....	7
2.1 Definitions & Concepts	7

2.1.1 CO ₂ Emission	7
2.1.2 Renewable Energy Consumption	8
2.1.3 Fossil Fuel Energy Consumption	8
2.1.4 Green Finance	9
2.1.5 Institutional Quality.....	10
2.1.6 Research & Development (R&D) Expenditure.....	10
2.1.7 Population Growth	11
2.1.8 GDP Growth.....	12
2.1.9 GDP Per Capita Growth	12
2.1.10 Foreign Direct Investment (FDI).....	13
2.2 Impact of Renewable Energy Consumption on CO ₂ Emissions	13
2.3 Impact of Fossil Fuel Energy Consumption on CO ₂ Emissions	15
2.4 Impact of Green Finance on CO ₂ Emission	16
2.5 Impact of Institutional Quality on CO ₂ Emission	18
2.6 Impact of Research & Development Expenditure (R&D) on CO ₂ Emission.....	20
2.7 Impact of Population Growth, GDP Growth, GDP Per Capita Growth, and Foreign Direct Investment (FDI) on CO ₂ Emission	22
2.8 Theoretical Background.....	23
2.9 Conceptual Framework.....	24
2.10 Chapter Summary	26
Chapter 3.....	27
RESEARCH METHODOLOGY	27
3.0 Introduction.....	27
3.1 Research Onion Overview	27
3.1.1 Research Philosophy: Positivism	27

3.1.2 <i>Research Approach: Deductive Approach</i>	28
3.1.3 <i>Methodological Choice: Quantitative Method</i>	28
3.2 <i>Research Strategy</i>	29
3.3 <i>Time Horizon: Longitudinal Design</i>	29
3.4 <i>Population and Sampling</i>	30
3.4.1 <i>Research Population</i>	30
3.4.2 <i>Sampling Technique</i>	30
3.4.3 <i>Inclusion Criteria</i>	30
3.4.4 <i>Exclusion Criteria</i>	30
3.4.5 <i>Final Country Sample</i>	31
3.5 <i>Data Sources</i>	31
3.5.1 <i>World Development Indicators (WDI)</i>	31
3.5.2 <i>Worldwide Governance Indicators (WGI)</i>	32
3.5.3 <i>R&D Databases</i>	32
3.5.4 <i>Green Finance Proxy Data</i>	32
3.6 <i>Data Extraction and Cleaning</i>	32
3.7 <i>Model Specification</i>	33
3.8 <i>Variable Operationalization</i>	33
3.8.1 <i>Dependent Variable</i>	33
3.8.2 <i>Independent Variable</i>	33
3.8.3 <i>Control Variable</i>	34
3.9 <i>Data Analysis Techniques</i>	34
3.9.1 <i>Correlation Analysis</i>	34
3.9.2 <i>Panel Regression (FE/RE Models)</i>	34
3.9.3 <i>Robustness and Diagnostic Tests</i>	35

3.9.4 <i>Software Justification: Stata</i>	35
3.10 Reliability and Validity.....	35
3.11 Ethical Considerations.....	35
3.12 Limitations of Methodology.....	36
3.13 Chapter Summary.....	36
Chapter 4.....	37
DATA ANALYSIS AND FINDINGS.....	37
4.0 Introduction.....	37
4.1 Descriptive Statistics.....	37
4.2 Correlation Analysis and Multicollinearity Diagnostics.....	39
4.3 Panel Regression Results.....	41
4.3.1 <i>Interpretation of Key Results</i>	42
4.4 Robustness Checks and Diagnostic Tests.....	43
4.4.1 <i>Heteroskedasticity and Serial Correlation</i>	43
4.4.2 <i>Cross-Sectional Dependence</i>	43
4.4.3 <i>Alternative Specifications</i>	43
4.5 Findings in Relation to Hypotheses and Literature.....	44
4.6 Country-Specific Insights and Comparative Analysis.....	45
4.7 Policy Implications Derived from Empirical Findings.....	46
4.8 Chapter Summary.....	47
Chapter 5.....	48
CONCLUSION AND RECOMMENDATIONS.....	48
5.0 Introduction.....	48
5.1 Discussion of Major Findings.....	48
5.2 Conclusion.....	49

5.3 Research Implications.....	50
5.3.1 <i>Theoretical Implications</i>	50
5.3.2 <i>Practical Implications</i>	51
5.4 Limitations of the Study	52
5.5 Directions for Future Research.....	53
5.6 Recommendations.....	54
REFERENCES	56

Chapter 1

INTRODUCTION

The accelerating rise in global CO₂ emissions has become one of the most pressing environmental and economic challenges of the twenty-first century (Huang & Ren, 2024). As nations pursue industrial expansion, energy security, and technological advancement, the composition of energy consumption, financial structures supporting sustainability, and institutional arrangements increasingly determine emission trajectories (Kinyar & Bothongo, 2024). Understanding the drivers of CO₂ emissions is therefore essential for designing effective climate mitigation strategies. This study examines how renewable energy consumption, fossil fuel use, green finance, institutional quality, and research and development (R&D) expenditure shape emissions trends. Additionally, the analysis incorporates population growth, GDP growth, GDP per capita growth, and foreign direct investment (FDI) as control variables to provide a comprehensive and empirically robust understanding of the determinants of CO₂ emissions.

1.1 Background of the Study

Climate change has emerged as an unprecedented global threat, driven primarily by the continuous rise in carbon dioxide (CO₂) emissions from energy production, industrial expansion, and rapid urbanization (Aslan et al., 2024). As countries strive for economic development, the structure and scale of energy consumption have become central factors in understanding global emission patterns. Historically, economic growth has been closely linked with fossil fuel consumption, which has contributed significantly to environmental degradation (AlNemer et al., 2023). Despite international commitments under the Paris Agreement, global CO₂ levels continue to climb, highlighting the need to understand the complex interactions between energy choices, financial mechanisms, institutional frameworks, technological innovation, and demographic dynamics (Amer et al., 2024).

Renewable energy consumption has increasingly gained importance due to its potential to reduce dependence on conventional energy sources and support long-term decarbonization pathways (Jamel & Zhang, 2024). Numerous countries are investing heavily in solar, wind, hydro, and other renewable sources to diversify their energy portfolios. However, the actual impact of renewable energy on CO₂ emissions varies across regions, depending on energy policies, technological

capacity, and institutional environments (Almulhim et al., 2025). Conversely, fossil fuel energy consumption remains dominant in many nations due to affordability, availability, and infrastructural dependence, making it a major contributor to rising emissions. Understanding how these contrasting energy sources simultaneously influence emissions is fundamental to sustainable development planning (Raihan et al., 2023).

Green finance has recently emerged as a transformative mechanism to support environmentally responsible investments. Through green bonds, sustainability-linked loans, and climate financing initiatives, green finance channels capital towards low-carbon technologies and energy efficiency projects (Umar & Safi, 2023). Yet, the effectiveness of such financial instruments largely depends on institutional quality, regulatory transparency, policy enforcement, and governance structures. Countries with strong institutions are better positioned to implement and monitor environmentally aligned financial systems, thereby reducing CO₂ emissions more effectively (Almulhim et al., 2025).

Research and development (R&D) expenditure also plays a critical role in shaping emission outcomes. Technological innovations can enhance energy efficiency, promote clean energy technologies, and enable industries to reduce their carbon footprints (Mamkhezri & Khezri, 2024). Nations investing substantially in R&D often exhibit greater resilience in transitioning towards low-carbon economies. However, disparities in research capacity and technological readiness create uneven global progress (Jiang et al., 2024).

Demographic and economic factors further complicate the emission landscape. Rapid population growth increases energy demand, urban expansion, and consumption levels (Rehman et al., 2022). Meanwhile, GDP growth and GDP per capita growth often stimulate industrialization and resource use, potentially increasing emissions unless supported by sustainable strategies (Mirziyoyeva & Salahodjaev, 2023; Awan & Azam, 2022). Foreign direct investment (FDI) also influences emissions, sometimes by transferring clean technologies, and other times by shifting pollution-intensive industries to developing countries (Yi et al., 2023).

Given these interconnected dynamics, a holistic understanding of the drivers of CO₂ emissions is essential for designing integrated policy interventions. This study addresses this need by jointly examining energy consumption patterns, financial mechanisms, institutional environments,

innovation capacity, and macroeconomic variables, offering a comprehensive perspective on the determinants of CO₂ emissions in the contemporary global context.

1.2 Research Gap

Existing literature on CO₂ emission drivers offers substantial insights but remains fragmented across thematic areas (Kinyar & Bothongo, 2024; Raihan et al., 2023). Prior studies have extensively examined the relationship between economic growth and emissions, often relying on the Environmental Kuznets Curve (EKC) framework. Similarly, the impact of energy consumption on emissions has been widely explored, yet most research isolates renewable or fossil fuel consumption rather than analyzing both simultaneously within an integrated model (Kinyar & Bothongo, 2024; Huang & Ren, 2024). The rapid rise of green finance and its potential role in reducing emissions have gained attention only in recent years (Zhao et al., 2023), leaving limited empirical evidence on its long-term influence, especially when assessed jointly with institutional quality and R&D expenditure (Nguyen & Dang, 2024; Jiang et al., 2024).

Furthermore, existing studies often neglect the combined moderating or reinforcing effects of institutional arrangements, technological innovation, and demographic pressures. Majority of research incorporates only a narrow set of control variables, leaving gaps in understanding how population dynamics, GDP per capita growth, and FDI collectively shape emission outcomes (Mirziyoyeva & Salahodjaev, 2023; Rehman et al., 2022). Additionally, research tends to focus on either developed or developing regions, limiting generalizability across different economic contexts.

Therefore, an evident gap exists in providing a comprehensive, multi-variable, and empirically robust assessment that integrates energy, financial, institutional, technological, demographic, and macroeconomic determinants of CO₂ emissions within a single analytical framework. This study addresses this gap directly.

1.3 Problem Statement

Despite increasing global commitments to climate action-such as the Paris Agreement and the United Nations Sustainable Development Goals-carbon dioxide (CO₂) emissions continue to rise, posing a significant threat to environmental stability and human well-being. This persistent increase underscores a critical disconnect between policy intentions and tangible emission

reductions, revealing a complex and inadequately understood web of driving factors (Jamel & Zhang, 2024; AlNemer et al., 2023). While prior research has identified several individual determinants of CO₂ emissions—such as energy consumption patterns, economic growth, and population dynamics, these studies often examine variables in isolation, overlooking their interconnected and simultaneous influences.

1.4 Research Rationale

Understanding the drivers of CO₂ emissions has become increasingly urgent as nations attempt to balance economic growth with environmental sustainability. Decisions related to energy consumption, financial systems, governance structures, and technological investment significantly influence emission patterns, yet their combined effects remain insufficiently explored. This study provides a timely and relevant contribution by integrating these variables into a single analytical framework. The inclusion of renewable and fossil fuel energy consumption allows the research to capture the dual nature of global energy transitions, while green finance and institutional quality introduce important governance and financial perspectives commonly overlooked in prior studies.

Incorporating R&D expenditure highlights the importance of innovation in achieving long-term decarbonization, especially for countries aiming to shift towards knowledge-based economies. Moreover, demographic and macroeconomic control variables—population growth, GDP growth, GDP per capita growth, and FDI—ensure a more accurate representation of real-world emission dynamics. By offering comprehensive empirical evidence, the study supports policymakers, researchers, and financial institutions in designing more targeted and effective mitigation strategies. Finally, this research addresses a critical academic and practical need by providing an integrated assessment that enhances understanding of CO₂ emission drivers in a rapidly evolving global context.

1.5 Research Aim

The aim of this study is to conduct a comprehensive assessment of CO₂ emission drivers by analyzing the impact of renewable energy consumption, fossil fuel consumption, green finance, institutional quality, and R&D expenditure. The study additionally evaluates population growth, GDP indicators, and FDI as control variables to develop an integrated understanding of the determinants of CO₂ emissions.

1.6 Research Objectives

Following are the research objectives of current study:

- To examine the effect of renewable energy consumption on CO₂ emissions.
- To analyze the impact of fossil fuel energy consumption on CO₂ emissions.
- To assess the contribution of green finance to CO₂ emission reduction.
- To evaluate the influence of institutional quality on CO₂ emission trends.
- To investigate the role of R&D expenditure in shaping CO₂ emission outcomes.

1.7 Research Questions

Based on these objectives, the central research question is:

1. **How does** renewable energy consumption influence CO₂ emissions?
2. What is the impact of fossil fuel energy consumption on CO₂ emissions?
3. To what extent does green finance contribute to reducing CO₂ emissions?
4. **How does** institutional quality shape the relationship between economic activities and CO₂ emissions?
5. What role does R&D expenditure play in mitigating or intensifying CO₂ emissions?

1.8 Research Significance

This study holds substantial theoretical and practical significance by offering a comprehensive examination of the diverse drivers influencing CO₂ emissions.

1.8.1 Theoretical Significance

From a theoretical perspective, the research contributes to environmental economics literature by integrating multiple variable energy consumption patterns, green finance, institutional quality, and R&D expenditure into a single empirical framework. This holistic approach advances existing knowledge beyond traditional models, which often examine these factors in isolation. The study also enriches discussions on sustainable development by exploring how governance, technological innovation, and macroeconomic forces jointly shape emission dynamics, thereby providing fresh insights into multidisciplinary climate research.

1.8.2 Practical Significance

From a practical standpoint, the findings offer valuable guidance for policymakers, environmental regulators, and financial institutions seeking to develop effective decarbonization strategies. Understanding the relative influence of renewable and fossil fuel consumption helps governments prioritize energy transition policies. Insights into green finance and institutional quality provide direction for strengthening government systems and promoting climate-aligned financial mechanisms. Additionally, identifying how demographic and economic factors contribute to emissions assists national planning authorities in crafting balanced and sustainable development strategies. Finally, the study delivers evidence-based recommendations that support the design of integrated, long-term climate policies tailored to contemporary global challenges.

1.9 Thesis Structure

This research study is organized into five chapters.

Chapter One introduces the study, presents the background, outlines the research gap, and defines the research aim, questions, and significance.

Chapter Two provides a comprehensive review of relevant literature and theoretical foundations relating to CO₂ emission drivers.

Chapter Three outlines the research methodology, including data sources, model specification, and analytical procedures.

Chapter Four presents and interprets empirical findings.

Chapter Five concludes the study, summarizes key results, discusses policy implications, highlights limitations, and proposes directions for future research.

1.10 Chapter Summary

This chapter introduced the study by outlining its background, research gaps, rationale, aim, questions, and significance. It established the importance of examining multiple drivers of CO₂ emissions within a unified framework. The next chapter builds on this foundation by presenting a detailed review of relevant literature and theoretical perspectives.

Chapter 2

LITERATURE REVIEW

2.0 Introduction

This chapter reviews existing literature relevant to the determinants of CO₂ emissions and the variables incorporated in this study. It synthesizes scholarly evidence on renewable energy consumption, fossil fuel use, green finance, institutional quality, and research and development (R&D) expenditure, alongside demographic and economic control variables. The chapter also explores theoretical foundations underpinning emission dynamics and environmental decision-making. By examining empirical findings, conceptual arguments, and methodological patterns across studies, this chapter lays the groundwork for developing hypotheses and establishing the analytical framework guiding the present research. Finally, it provides a comprehensive basis for understanding the multifaceted drivers of CO₂ emissions.

2.1 Definitions & Concepts

2.1.1 CO₂ Emission

CO₂ emission refers to the release of carbon dioxide gas into the atmosphere as a result of human activities such as fuel combustion, industrial production, transportation, and land-use changes. It is the most significant greenhouse gas contributing to global warming, accounting for the largest share of anthropogenic emissions worldwide (Adebayo et al., 2022). CO₂ emissions serve as a key indicator of environmental degradation and climate change, making them central to global sustainability research and policy frameworks. In environmental economics literature, CO₂ emissions are commonly used to measure a country's environmental performance, ecological footprint, and progress toward decarbonization (Aslan et al., 2024).

Scholars emphasize that CO₂ emissions are closely linked to economic structure, energy choices, and technological advancement. Countries that are heavily reliant on fossil fuels typically exhibit higher emission levels, whereas those investing in renewable energy, green technologies, and energy efficiency demonstrate reduced emission trajectories (Jamel & Zhang, 2024). CO₂ emissions also interact with demographic and macroeconomic factors, including population density, industrialization levels, and consumption patterns. Monitoring and analyzing CO₂

emissions is essential for evaluating environmental policies, assessing the effectiveness of mitigation strategies, and understanding the long-term impacts of economic development on climate systems. In empirical research, CO₂ emissions are frequently measured in metric tons per capita, total CO₂ output, or emissions intensity relative to GDP (Almulhim et al., 2025).

2.1.2 Renewable Energy Consumption

Renewable energy consumption refers to the use of energy derived from naturally replenishing sources such as solar, wind, hydro, geothermal, and biomass. Unlike fossil fuels, renewable energy does not deplete finite natural resources and typically generates significantly lower CO₂ emissions, making it a critical element in global climate mitigation strategies (AlNemer et al., 2023). In academic literature, renewable energy consumption is widely recognized as a catalyst for sustainable development, as it reduces environmental pollution, enhances energy security, and supports long-term economic resilience. The growth of renewable energy technologies is often linked to advancements in innovation, favorable government policies, cost reductions, and public awareness of climate change (Kinyar & Bothongo, 2024).

Empirical evidence consistently shows that increased adoption of renewable energy contributes to the decarbonization of power systems, particularly in countries that prioritize clean energy investments. However, scholars also note that the magnitude of environmental benefits depends on grid integration capacity, energy storage systems, regulatory environments, and technological maturity (Grodzicki & Jankiewicz, 2022). The transition from fossil fuels to renewables requires substantial institutional support, financial incentives, and stable policy frameworks. In empirical studies, renewable energy consumption is typically measured as a share of total energy use, illustrating the extent to which countries are progressing toward cleaner and more sustainable energy systems (Ullah & Lin, 2024).

2.1.3 Fossil Fuel Energy Consumption

Fossil fuel energy consumption refers to the use of non-renewable energy sources such as coal, oil, and natural gas for electricity generation, industrial processes, heating, and transportation. These energy sources are formed from ancient organic matter and have historically powered global economic growth due to their affordability, availability, and high energy density (Huang & Ren, 2024). However, fossil fuels are the primary contributors to CO₂ emissions, releasing large

quantities of greenhouse gases when combusted. In academic literature, fossil fuel consumption is consistently associated with environmental degradation, climate change, and air pollution. Countries with high industrial activity or limited renewable energy infrastructure often remain heavily dependent on fossil fuels, resulting in elevated emission levels (Raihan et al., 2023).

Scholars also highlight that fossil fuel reliance persists due to entrenched energy systems, subsidy structures, and technological lock-in, which slow the transition to cleaner alternatives. Despite global commitments to carbon reduction, fossil fuels retain a dominant share in many national energy portfolios, especially in developing economies (Rehman et al., 2019). Measuring fossil fuel consumption typically involves evaluating its share of total energy use or sector-specific consumption patterns. Understanding the dynamics of fossil fuel consumption is essential for designing effective climate policies, promoting energy diversification, and addressing the long-term environmental consequences of carbon-intensive development (Li & Haneklaus, 2021).

2.1.4 Green Finance

Green finance refers to financial instruments, investments, and policies designed to support environmentally sustainable projects, climate mitigation initiatives, and low-carbon economic activities. It encompasses mechanisms such as green bonds, sustainability-linked loans, climate funds, carbon trading schemes, and environmentally focused banking practices (Zhao et al., 2023). Green finance aims to mobilize capital towards renewable energy projects, energy efficiency improvements, green infrastructure, and pollution control technologies. In scholarly literature, green finance is increasingly recognized as a critical driver for transitioning toward a sustainable and climate-resilient economy (Jamel & Zhang, 2024).

Researchers emphasize that effective green finance requires strong institutional support, regulatory frameworks, financial disclosure standards, and stakeholder collaboration. Green finance promotes innovation, reduces financing gaps for clean technologies, and encourages firms and governments to adopt environmentally responsible practices. Its expansion depends on investor confidence, policy consistency, and market maturity (Meo & Abd Karim, 2022). Empirical studies show that green finance can significantly reduce CO₂ emissions by facilitating the adoption of clean technologies and enabling the replacement of carbon-intensive energy systems. However, challenges such as greenwashing, inadequate transparency, and limited access in developing countries hinder its full potential. Green finance is typically measured through the volume of green

financial instruments, investment flows into environmental projects, or policy indices capturing climate finance readiness (Nawaz et al., 2021).

2.1.5 Institutional Quality

Institutional quality refers to the effectiveness, transparency, and stability of governance systems, regulatory frameworks, and public institutions within a country. It encompasses dimensions such as rule of law, government effectiveness, control of corruption, regulatory quality, political stability, and accountability (Yang et al., 2022). High institutional quality ensures efficient policy implementation, protection of property rights, and fair enforcement of environmental regulations. In environmental economics, institutional quality is considered a critical determinant of sustainable development outcomes because strong institutions enable consistent climate policies, reduce uncertainty, and promote investment in clean technologies (Halder & Sethi, 2021).

Research shows that countries with robust institutions are more likely to adopt efficient energy systems, enforce emission standards, and support renewable energy development. Conversely, weak institutional frameworks often lead to corruption, inadequate enforcement, and misallocation of resources, contributing to higher CO₂ emissions (Adedoyin et al., 2022). Institutional quality also influences the effectiveness of green finance, innovative policies, and environmental regulations. It is commonly measured using indicators from the Worldwide Governance Indicators (WGI) or similar governance indices (Almulhim et al., 2025). The role of institutional quality in environmental performance is widely recognized, as it shapes policy outcomes, market behaviour, and the long-term success of decarbonization strategies. Understanding institutional quality is therefore essential for assessing emission dynamics across different national contexts.

2.1.6 Research & Development (R&D) Expenditure

Research and development (R&D) expenditure refers to financial resources allocated to creative and systematic activities aimed at developing new knowledge, technologies, or processes. In the context of environmental sustainability, R&D plays a crucial role in fostering innovations that enhance energy efficiency, reduce emissions, and enable the adoption of clean technologies (Han et al., 2023). R&D investment supports advancements in renewable energy, carbon capture systems, smart grids, and low-carbon industrial processes. The literature highlights that countries with higher R&D spending tend to achieve faster technological progress, enabling smoother

transitions toward green economic models (Jiang et al., 2024). R&D also contributes to lowering costs of renewable technologies, improving their competitiveness relative to fossil fuels. However, the effectiveness of R&D in reducing emissions depends on supportive policy environments, institutional efficiency, and technology diffusion capabilities (Sheikh & Hassan, 2023).

Some scholars argue that R&D may initially increase emissions due to industrial activities associated with research processes, though long-term impacts are typically positive (Petrović & Lobanov, 2020). R&D expenditure is commonly measured as a percentage of GDP or through sector-specific innovation indicators. Its role in shaping CO₂ emissions is increasingly studied, as innovation-driven economies rely heavily on technological solutions to achieve climate goals (Mamkhezri & Khezri, 2024). Understanding R&D expenditure is therefore essential for assessing the potential of innovation-led decarbonization pathways.

2.1.7 Population Growth

Population growth refers to the increase in the number of individuals within a country over time, driven by birth rates, death rates, and migration patterns. It significantly influences energy demand, resource consumption, and environmental pressures. As population increases, demand for housing, transportation, agriculture, and industrial production rises, leading to higher energy use and CO₂ emissions (Shaari et al., 2021). Literature consistently links population growth with environmental degradation, particularly in countries experiencing rapid urbanization and industrial expansion. Researchers emphasize that population growth intensifies energy consumption patterns, especially in developing economies with limited access to clean energy technologies (Rehman et al., 2022).

However, some scholars argue that population growth can be managed sustainably when accompanied by strong institutional frameworks, technological innovation, and efficient resource management. Population growth also interacts with economic growth, urban density, and lifestyle choices, shaping long-term emission trajectories. It is typically measured as the annual percentage increase in population (Shaari et al., 2021). Understanding population dynamics is essential for environmental planning and for designing policies aimed at reducing per capita emissions. As a control variable, population growth helps isolate the independent effects of energy, financial, and institutional factors on CO₂ emissions.

2.1.8 GDP Growth

GDP growth refers to the increase in the value of goods and services produced within a country over a specific period. It reflects economic expansion, industrialization, and improvements in living standards. GDP growth is often associated with increased energy consumption and production activities, which can result in higher CO₂ emissions, especially in economies reliant on fossil fuels (Mirziyoyeva & Salahodjaev, 2023). The Environmental Kuznets Curve (EKC) theory suggests that emissions rise during early stages of economic growth but eventually decline as income levels increase and countries adopt cleaner technologies (Onofrei et al., 2022). However, empirical evidence on the EKC remains mixed, with outcomes varying across regions and development levels.

Scholars note that the relationship between GDP growth and CO₂ emissions depends on energy efficiency, technological adoption, structural transformation, and environmental regulations. In developing economies, GDP growth typically correlates with rising emissions due to expansion of manufacturing, construction, and transportation sectors. In contrast, advanced economies may decouple growth from emissions by shifting toward service sectors and clean energy. GDP growth is usually measured as an annual percentage change in real GDP (Onofrei et al., 2022). As a control variable, GDP growth allows researchers to account for economic activity when assessing other drivers of CO₂ emissions.

2.1.9 GDP Per Capita Growth

GDP per capita growth measures the increase in average economic output per person and is widely used as an indicator of living standards and economic well-being. It reflects changes in income distribution, productivity, and resource availability. In environmental research, GDP per capita growth is often linked to energy consumption patterns, technological adoption, and household-level environmental behaviors (Awan & Azam, 2022). Higher income levels typically lead to increased consumption of goods, transportation, and energy-intensive services, potentially raising CO₂ emissions. However, wealthier countries may also invest more in clean technologies, environmental regulations, and sustainable infrastructure, leading to long-term reductions in emissions (Yunita et al., 2023).

The impact of GDP per capita growth on emissions is therefore context-dependent, influenced by institutional quality, cultural factors, and national energy policies. Some studies support the Environmental Kuznets Curve theory, suggesting a non-linear relationship between income and emissions, while others find continuous positive associations. GDP per capita growth is commonly measured as the annual percentage change in GDP divided by population (Awan & Azam, 2022). As a control variable, it helps isolate the effects of structural economic changes and individual consumption patterns on CO₂ emission dynamics.

2.1.10 Foreign Direct Investment (FDI)

Foreign direct investment (FDI) refers to cross-border investments made by firms or individuals in business operations, assets, or production facilities of another country. FDI plays a significant role in technology transfer, industrial development, and economic integration. Its environmental impact is widely debated in literature (Rahaman et al., 2022). The “pollution haven theory” suggests that multinational firms may relocate pollution-intensive industries to countries with lax environmental regulations, increasing CO₂ emissions. Conversely, the “pollution halo theory” argues that FDI can reduce emissions by introducing cleaner technologies, advanced management practices, and higher environmental standards (Yi et al., 2023).

The effect of FDI on emissions depends on host-country regulations, institutional quality, and industrial structure. Developing economies often experience mixed outcomes due to variability in enforcement capacity and technological readiness. FDI is typically measured as net inflows relative to GDP (Yi et al., 2023). As a control variable, it helps capture external economic influences on emission dynamics, particularly those arising from globalization and industrial relocation.

2.2 Impact of Renewable Energy Consumption on CO₂ Emissions

Renewable energy consumption has emerged as one of the most influential determinants of CO₂ emission reduction, receiving extensive scholarly attention due to its relevance for climate policy and sustainable development (Sahoo & Sahoo, 2022). Renewable energy sources such as solar, wind, hydro, geothermal, and biomass generate electricity with significantly lower environmental impacts compared to fossil fuels. As a result, increasing renewable energy consumption is widely regarded as a critical strategy for achieving long-term decarbonization (AlNemer et al., 2023).

Numerous studies demonstrate a strong negative relationship between renewable energy usage and CO₂ emissions, indicating that higher penetration of renewables plays a vital role in reducing environmental degradation. These findings are especially prominent in countries that have implemented strong policy frameworks, technological innovation, and financial incentives supporting clean energy transitions (Amer et al., 2024).

Several empirical studies using panel data analysis identify renewable energy as a key variable responsible for lowering emissions across developed and developing economies. Some researchers argue that renewable energy substitutes carbon-intensive sources, resulting in direct reductions in emissions. Others highlight indirect benefits, such as improved energy efficiency, reduced reliance on imported fossil fuels, and promotion of green employment, which further support environmental sustainability (Ullah & Lin, 2024). However, the impact of renewable energy depends heavily on grid integration capacity, technological readiness, and institutional effectiveness. Countries with advanced energy infrastructure and stable governance systems tend to gain more substantial benefits from renewable energy expansion (Grodzicki & Jankiewicz, 2022).

Despite the generally positive outlook, some researchers highlight short-term limitations associated with renewable energy adoption. Intermittency challenges, storage constraints, and initial investment costs can hinder the immediate effectiveness of renewable solutions (Adebayo et al., 2022). In some contexts, renewable energy may coexist with fossil fuels rather than replace them, leading to less significant reductions in emissions. However, even in these cases, renewable energy contributes to long-term decarbonization by diversifying national energy portfolios and gradually reducing dependency on fossil fuels (Kinyar & Bothongo, 2024).

Regional heterogeneity also shapes the renewable energy–emissions relationship. For instance, European Union countries exhibit strong negative effects due to ambitious climate policies, whereas some developing countries experience weaker impacts due to infrastructural and financial constraints. Nevertheless, most studies agree that renewable energy consumption is a vital component of global climate mitigation strategies (Kinyar & Bothongo, 2024).

A growing body of literature also emphasizes the role of green finance, institutional quality, and technological innovation in strengthening the effectiveness of renewable energy. Countries with stable financial systems and transparent institutions can attract investment for renewable energy

projects, accelerating the decarbonization process. Meanwhile, advancements in R&D help reduce the cost of renewable technologies, making them more competitive with fossil fuels (Kahia et al., 2019).

The literature overwhelmingly supports the view that renewable energy consumption significantly reduces CO₂ emissions when supported by strong institutions, innovative capacity, and favorable policy frameworks. Renewable energy remains a cornerstone of global efforts to combat climate change and transition toward low-carbon economies. Based on above literature, it is hypothesized that:

***Hypothesis 1:** Renewable energy consumption has a significant negative impact on CO₂ emissions.*

2.3 Impact of Fossil Fuel Energy Consumption on CO₂ Emissions

Fossil fuel energy consumption is widely recognized as the primary driver of rising CO₂ emissions and global climate change. Fossil fuels, including coal, oil, and natural gas, have historically served as the dominant sources of energy for industrial production, transportation, electricity generation, and residential heating (Li & Haneklaus, 2021). Their combustion releases large quantities of CO₂, making fossil fuel consumption strongly and positively associated with environmental degradation. The literature provides overwhelming empirical evidence demonstrating that fossil fuel dependence significantly increases CO₂ emissions across countries, sectors, and income groups (Huang & Ren, 2024). This relationship remains consistent regardless of the econometric models or time periods examined.

Research highlights that coal consumption, in particular, has the most detrimental effects due to its high carbon intensity. Countries heavily reliant on coal-fired power plants tend to experience the highest emission levels (Aslan et al., 2024). Oil consumption is also strongly linked with transport-related emissions, while natural gas, although cleaner than coal and oil, still contributes substantially to CO₂ levels. Scholars argue that global reliance on fossil fuels persists due to entrenched energy infrastructures, economic dependence, technological lock-in, and ongoing subsidies that reduce the cost of fossil fuel consumption relative to renewable alternatives (Rehman et al., 2022).

Studies emphasize that developing countries often experience faster growth in fossil fuel consumption due to rapid industrialization and urbanization, leading to substantial increases in emissions (Rehman et al., 2019). Meanwhile, developed economies with advanced clean energy technologies may experience a slower rate of fossil fuel growth, yet their long historical dependence amplifies cumulative CO₂ emissions. The expansion of energy-intensive industries, transportation networks, and manufacturing sectors further increases fossil fuel demand, making it difficult for countries to shift toward low-carbon pathways (Raihan et al., 2023).

Institutional quality also plays a critical role in shaping fossil fuel–emissions dynamics. Countries with weak regulatory frameworks and corruption often struggle to implement environmental policies, resulting in unchecked fossil fuel consumption. Conversely, strong institutions can enforce emission standards, promote renewable alternatives, and reduce fossil fuel dependence. Green finance initiatives similarly help channel investment away from fossil fuels and toward sustainable technologies (Huang & Ren, 2024).

Several studies also highlight potential rebound effects, where energy efficiency improvements paradoxically increase fossil fuel consumption by reducing energy costs. This suggests that technological improvements alone are insufficient without accompanying policy interventions. Additionally, geopolitical factors such as oil prices, supply chain stability, and international energy agreements influence fossil fuel consumption patterns and emission outcomes (Raihan et al., 2023).

Despite growing awareness of climate change, fossil fuels continue to dominate global energy markets, posing challenges for CO₂ reduction goals. Literature consistently reinforces the need for structural reforms, renewable energy transition policies, and market incentives to mitigate the environmental impact of fossil fuels. The empirical evidence strongly supports the positive relationship between fossil fuel consumption and CO₂ emissions. Based on above literature, it is hypothesized that:

***Hypothesis 2:** Fossil fuel energy consumption has a significant positive impact on CO₂ emissions.*

2.4 Impact of Green Finance on CO₂ Emission

Green finance has become an essential mechanism for facilitating the transition toward low-carbon development by directing financial resources toward environmentally sustainable projects. It

includes instruments such as green bonds, green loans, environmental credit lines, carbon financing, and sustainability-linked investments (Zhao et al., 2023). These mechanisms channel capital toward renewable energy deployment, energy-efficient infrastructure, waste management, low-carbon transportation, green buildings, and climate adaptation initiatives. The central premise in green finance literature is that increased financial support for environmentally friendly activities significantly reduces CO₂ emissions by encouraging the adoption of cleaner technologies, accelerating decarbonization processes, and reducing reliance on fossil-fuel-intensive development strategies (Jamel & Zhang, 2024).

Empirical research provides consistent evidence that green finance contributes to mitigating climate change, although the magnitude varies across countries. Studies on green bonds show that countries with developed green bond markets experience measurable declines in carbon emissions due to increased investment in clean energy and low-carbon industrial practices (Meo & Abd Karim, 2022). Moreover, large-scale renewable energy projects often require substantial upfront capital investment, which green finance helps supply. By lowering financial constraints and enhancing access to climate-related funding, green finance enables firms and governments to adopt cleaner energy sources, modernize infrastructure, and implement energy-efficient technologies. As a result, emissions intensity is expected to decline over time (Umar & Safi, 2023).

Green finance also plays an important role in influencing corporate behaviour. Firms receiving green financing are incentivized to adopt environmental disclosure standards, implement climate-friendly strategies, and commit to sustainable operations to maintain investor confidence. Some studies emphasize the signaling effect where companies with access to green funds improve their environmental performance to preserve reputational advantages (Zhou et al., 2020). Furthermore, green finance reduces the cost of capital for environmentally responsible firms, thereby promoting investments in innovation, clean technologies, and green R&D. These structural changes foster long-term reductions in CO₂ emissions by reshaping industrial practices and encouraging energy transitions (Nawaz et al., 2021).

At the macroeconomic level, green finance supports national sustainability agendas by aligning public and private sector investments with climate-mitigation objectives. Governments implementing green taxonomies, climate funds, and ecological financial guidelines provide stable frameworks for green investment flows. These regulatory structures increase investor confidence

and scale up financial participation in green projects. Consequently, green finance helps transform energy systems, promote sustainable consumption patterns, and expand green industry value chains (Umar & Safi, 2023).

However, some scholars argue that the effectiveness of green finance depends on institutional capacity, market transparency, environmental governance, and green-investment monitoring. In countries with weak regulatory oversight, greenwashing risks may undermine environmental gains. These conditions highlight the importance of robust governance systems to ensure that green financial flows genuinely reduce emissions (Zhao et al., 2023).

The literature establishes that green finance acts as a catalyst for lowering carbon emissions by supporting renewable energy expansion, promoting clean technologies, incentivizing responsible corporate practices, and enabling sustainable economic transformation. Therefore, it is expected that higher levels of green finance reduce CO₂ emissions significantly. Based on above literature, it is hypothesized that:

***Hypothesis 3:** Green finance has a negative and significant impact on CO₂ emissions.*

2.5 Impact of Institutional Quality on CO₂ Emission

Institutional quality is widely recognized as a fundamental determinant of environmental outcomes, influencing the design, enforcement, and effectiveness of environmental policies. It encompasses dimensions such as regulatory quality, rule of law, government effectiveness, political stability, control of corruption, and democratic accountability (Yang et al., 2022). Strong institutions facilitate coherent environmental governance, ensure compliance with environmental standards, promote technological adoption, and support long-term sustainability planning. Conversely, weak institutions often lead to regulatory failures, environmental degradation, and ineffective climate-mitigation strategies (Nguyen & Dang, 2024).

The literature consistently demonstrates that higher institutional quality contributes to reduced CO₂ emissions by enhancing environmental policy implementation and encouraging sustainable development practices (Haldar & Sethi, 2021). Strong regulatory frameworks enable governments to impose emissions standards, enforce penalties for environmental violations, and promote cleaner production processes. Countries with high institutional quality typically adopt stringent environmental legislation, ensuring industries comply with pollution-control requirements. As a

result, institutional strength acts as a mechanism that decreases emissions intensity (Almulhim et al., 2025).

Institutional quality also affects the efficiency of energy systems. Well-functioning governments are more capable of supporting renewable energy markets, managing large-scale energy transitions, and integrating green technologies. Effective institutions reduce bureaucratic inefficiencies, streamline renewable-energy project approvals, and attract green investments. These favorable conditions accelerate the deployment of clean energy technologies, which in turn lowers CO₂ emissions by replacing fossil-fuel-dependent systems (Salman et al., 2019).

Corruption control is another essential institutional dimension that influences environmental outcomes. High corruption levels often lead to lax enforcement of environmental regulations, allowing firms to engage in polluting activities without penalties. This undermines sustainability efforts and leads to unchecked emissions. Conversely, strong anti-corruption frameworks improve regulatory enforcement, ensuring firms adhere to environmental standards. Empirical evidence suggests that reducing corruption leads to measurable improvements in air quality and decreases in CO₂ emissions, particularly in developing economies (Adedoyin et al., 2022).

Institutional quality also contributes to effective resource allocation and supports environmental innovation. Countries with transparent governance and efficient institutions allocate financial resources more effectively toward low-carbon technologies, research, and climate adaptation. Institutional stability fosters favorable conditions for private-sector participation in green projects and encourages international environmental cooperation. Strong institutions also enhance public awareness, strengthen environmental education programs, and support community engagement in sustainable initiatives (Almulhim et al., 2025).

Nevertheless, literature highlights that the relationship between institutional quality and environmental performance may vary depending on economic development levels. In some lower-income countries, institutional constraints may limit the implementation of environmental policies even when regulations exist. In high-income countries, however, institutional capacity amplifies the effectiveness of technological innovation and environmental policy tools. Despite these variations, institutional quality is generally considered essential for achieving long-term CO₂ reduction (Yang et al., 2022).

To sum up, strong institutional quality functions as a crucial enabling factor for effective environmental governance, technological innovation, and sustainable energy transitions. By strengthening regulatory capacity and improving accountability, high institutional quality significantly reduces CO₂ emissions. Based on above literature, it is hypothesized that:

***Hypothesis 4:** Institutional quality has a negative and significant impact on CO₂ emissions.*

2.6 Impact of Research & Development Expenditure (R&D) on CO₂ Emission

Research and Development (R&D) expenditure is considered a pivotal driver of technological innovation, particularly in the fields of energy efficiency, renewable technologies, low-carbon production systems, and environmental management. In the context of environmental economics, R&D investment plays a dual role: it promotes technological progress while fostering cleaner industrial processes that gradually reduce carbon intensities (Han et al., 2023). Technological advancement enhances the efficiency of energy consumption, enabling firms and countries to produce more output with fewer emissions. Many scholars argue that innovation-driven strategies, supported by sustained R&D spending, provide long-term and sustainable pathways to reduce CO₂ emissions without compromising economic growth (Mamkhezri & Khezri, 2024). Thus, R&D investment is widely viewed as a mechanism that accelerates green transitions and enhances environmental sustainability.

A broad stream of empirical literature demonstrates a significant negative relationship between R&D expenditure and CO₂ emissions. For instance, Kihombo et al. (2021) found that eco-innovation, largely driven by research investment, significantly reduces emissions in both developed and developing countries. Similarly, Jiang et al. (2024) emphasized that R&D spending enhances renewable energy utilization and supports cleaner production frameworks, ultimately contributing to environmental improvement. Furthermore, countries with higher R&D intensity, especially in green technologies, tend to adopt advanced pollution-control equipment and carbon-efficient energy solutions more rapidly. This linkage underscores the importance of innovation in shaping climate policy and sustainable development agendas.

Conversely, some studies highlight that the impact of R&D on emissions may depend on how research outputs are utilized. For example, general R&D expenditure that prioritizes productivity enhancement rather than environmental innovation could inadvertently increase production-

related emissions in the short term (Petrović & Lobanov, 2020). Such mixed findings indicate that the type of R&D investment, whether oriented toward sustainable technologies or general economic competitiveness—determines its environmental implications. Nevertheless, when R&D is specifically channeled toward green innovations, literature overwhelmingly supports its effectiveness in emission reduction (Sheikh & Hassan, 2023).

Moreover, R&D contributes to environmental sustainability through the diffusion of clean technologies. Innovations in areas such as renewable energy systems, smart grids, carbon capture, energy-efficient machinery, hybrid vehicles, and digital energy optimization tools are direct outcomes of research investment. These innovations influence macro-level environmental performance by encouraging cleaner industrial structures and reducing reliance on emission-intensive energy sources. In line with the endogenous growth theory, technological progress spurred by R&D enhances long-term productivity while simultaneously improving environmental quality, aligning economic development with sustainability objectives (Sheikh & Hassan, 2023).

Additionally, high R&D spending fosters an enabling environment for green finance and policy incentives. Governments and private firms often link their R&D strategies with climate commitments, leading to regulatory frameworks that reward low-carbon innovations. Public funding for environmental R&D further supports research institutions, universities, and industries in generating climate-friendly solutions. Cross-border collaborations also promote the global diffusion of green technologies, reinforcing the positive role of R&D in mitigating environmental degradation (Jiang et al., 2024).

The literature supports the proposition that R&D investment plays a vital role in reducing CO₂ emissions by enhancing technological innovation, improving energy efficiency, and promoting green and sustainable production processes. Although some context-specific variations exist, the dominant empirical evidence confirms its long-term environmental benefits. Based on above literature, it is hypothesized that:

Hypothesis 5: Research and Development (R&D) expenditure has a significant negative impact on CO₂ emissions.

2.7 Impact of Population Growth, GDP Growth, GDP Per Capita Growth, and Foreign Direct Investment (FDI) on CO₂ Emission

Population growth, GDP growth, GDP per capita growth, and Foreign Direct Investment (FDI) represent key macroeconomic determinants influencing environmental outcomes. The relationship between population growth and CO₂ emissions has been widely discussed in ecological economics. Population expansion increases energy consumption, transportation, housing demand, and industrial production, thereby exerting pressure on environmental resources (Rehman et al., 2022). Empirical studies consistently find that higher population density correlates with elevated emission levels, especially in developing countries where urbanization and industrialization are rapidly expanding. However, improvements in technology and environmental regulations can moderate this effect, suggesting that population impact varies across development stages (Shaari et al., 2021).

GDP growth is traditionally associated with higher emissions due to increased industrial output, energy use, and transportation activities (Onofrei et al., 2022). The Environmental Kuznets Curve (EKC) framework posits that emissions initially rise with economic growth but decline once countries achieve higher income levels and adopt cleaner technologies. Many studies support this inverted-U relationship, indicating that early-stage growth is emission-intensive, while later stages promote environmental improvements. The scale effect implies that growth increases emissions, the composition effect suggests structural changes toward less carbon-intensive sectors, and the technique effect highlights the adoption of cleaner technologies. GDP growth influences emissions through these interconnected pathways (Mirziyoyeva & Salahodjaev, 2023).

GDP per capita growth additionally reflects individual consumption behaviour and lifestyle patterns. Higher income levels typically increase demand for vehicles, appliances, and energy-intensive goods, contributing to greater emissions (Awan & Azam, 2022). Yet, wealthier societies often invest in renewable energy, environmental regulations, and green technologies, allowing emissions to stabilize or decline over time. Several studies provide evidence that GDP per capita growth has a nonlinear effect on emissions depending on a country's development stage, institutional capacity, and environmental policy framework (Yunita et al., 2023).

Foreign Direct Investment (FDI) is another influential factor with both positive and negative effects on environmental quality. The pollution haven theory suggests that multinational firms shift

emission-intensive production to countries with lax environmental regulations, resulting in higher CO₂ emissions (Rahaman et al., 2022). In contrast, the pollution halo theory argues that foreign investors bring advanced technologies and managerial practices that improve environmental performance in host countries. Empirical results remain mixed, with some studies showing that FDI increases emissions in developing economies, while others highlight technology transfer and efficiency improvements that reduce carbon intensity (Yi et al., 2023).

These macroeconomic variables play a structural role in shaping CO₂ emissions. Population growth increases resource demand, GDP and GDP per capita growth influence industrialization patterns and consumption behaviors, while FDI affects emissions based on regulatory and technological conditions. Collectively, these variables help explain long-term emission dynamics and are therefore essential for comprehensive environmental analysis.

2.8 Theoretical Background

The Environmental Kuznets Curve (EKC) theory provides a widely accepted framework for understanding the relationship between economic development and environmental degradation, particularly CO₂ emissions. First proposed by Grossman and Krueger (1995), the EKC posits that the relationship between income and environmental impact follows an inverted-U shape. At early stages of economic growth, industrialization and increased energy consumption result in higher pollution and CO₂ emissions. As income rises, societies prioritize economic expansion over environmental quality, often relying on fossil fuels, energy-intensive industries, and resource exploitation. This stage is characterized by high emissions due to rapid industrial activity, population growth, and limited access to cleaner technologies (Zhang, 2021).

However, beyond a certain income threshold, EKC suggests that further economic development leads to environmental improvements. Higher-income societies demand cleaner environments, adopt advanced technologies, implement stricter environmental regulations, and invest in renewable energy and energy efficiency. This shift is facilitated by technological innovation, institutional effectiveness, and the availability of financial mechanisms that support sustainable development. EKC thus implies that economic growth can be compatible with environmental protection, provided that appropriate policies, technological, and institutional interventions are in place (Mahmood et al., 2023).


In the context of this study, the EKC theory underpins the inclusion of variables such as GDP growth, GDP per capita growth, population dynamics, energy consumption, green finance, institutional quality, and R&D expenditure. Fossil fuel consumption and industrialization represent the early-stage growth phase, typically increasing CO₂ emissions. In contrast, renewable energy adoption, green finance, institutional quality, and R&D reflect mechanisms that facilitate the decoupling of economic growth from environmental degradation in the later stage of the EKC. Population growth influences the scale effect by increasing demand for resources and energy, whereas institutional quality and R&D expenditure affect the technique effect, enabling cleaner production and more efficient energy use. Green finance further accelerates the transition to low-carbon pathways by providing targeted financial support for environmentally friendly technologies and projects (Leal & Marques, 2022).

Empirical studies applying the EKC framework often incorporate energy, institutional, and innovation variables to better explain variations in CO₂ emissions across countries and over time. By integrating these factors, the EKC theory supports a more detailed understanding of how economic, social, technological, and institutional forces jointly influence environmental outcomes. It highlights the critical role of policy, governance, and investment in shaping the turning point at which growth transitions from being environmentally harmful to environmentally sustainable (Lau et al., 2025).

To sum up, the EKC theory offers a coherent theoretical lens for this study by linking economic growth, energy consumption patterns, institutional quality, technological innovation, and financial mechanisms to CO₂ emissions. It provides the foundation for developing hypotheses that examine how renewable energy, fossil fuel consumption, green finance, institutional quality, R&D expenditure, and macroeconomic factors collectively determine emission trajectories, thus guiding the empirical investigation of environmental sustainability in contemporary economies.

2.9 Conceptual Framework

Based on literature and the developed hypotheses, the following conceptual framework is proposed for this study:



**Independent
Variables**

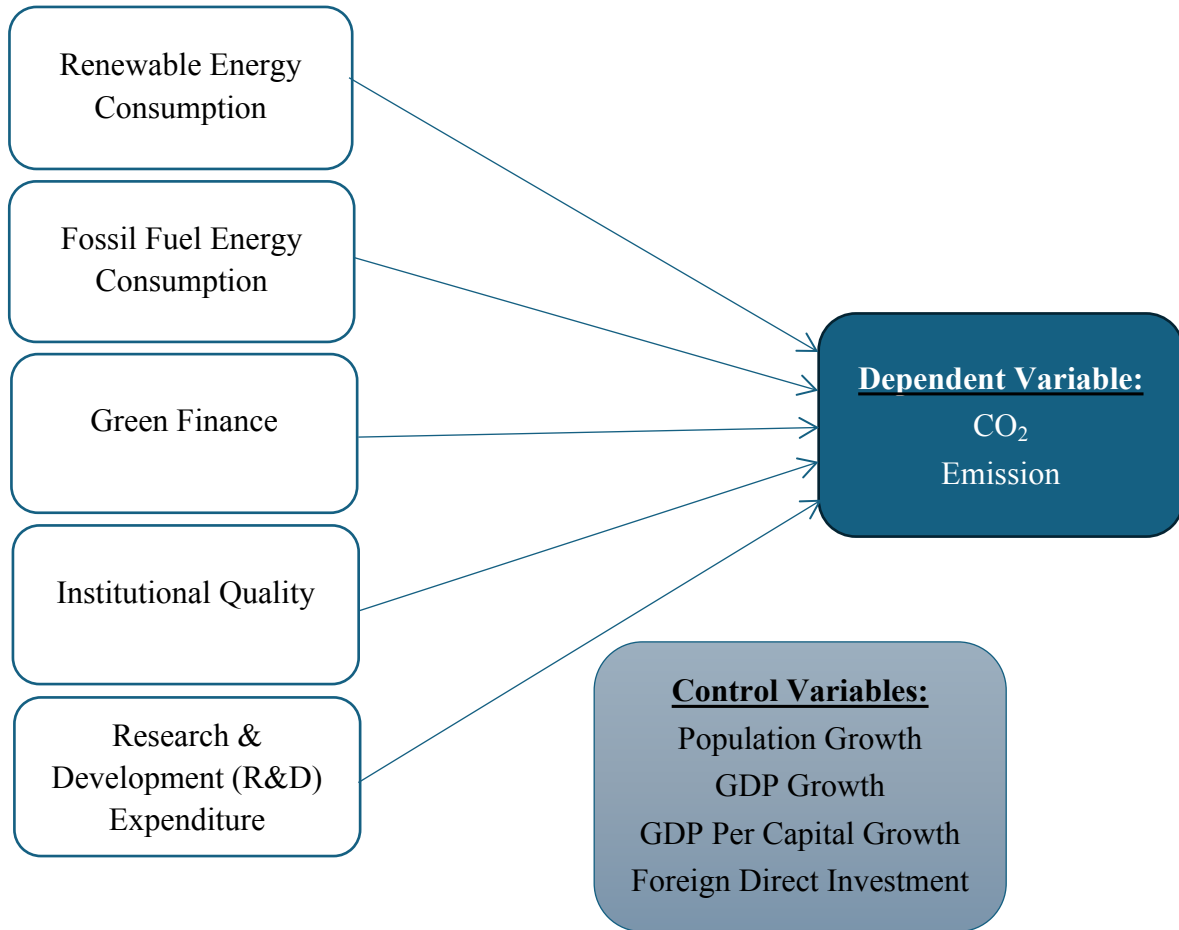


Figure 1: Conceptual Framework

The conceptual framework for this study is designed to illustrate the relationships between CO₂ emissions and its multiple determinants, integrating both economic and environmental perspectives. The framework positions CO₂ emissions as the dependent variable influenced by key independent variables: renewable energy consumption, fossil fuel energy consumption, green finance, institutional quality, and research and development (R&D) expenditure. Renewable energy consumption is hypothesized to reduce CO₂ emissions by replacing carbon-intensive energy sources, while fossil fuel consumption is expected to increase emissions due to its high carbon intensity.

Green finance provides the financial resources necessary for clean energy investments, energy-efficient technologies, and sustainable infrastructure, acting as a mitigating factor for emissions.

Institutional quality facilitates effective policy implementation, regulatory compliance, and environmental governance, enhancing the impact of sustainable practices. R&D expenditure contributes to innovation and technological advancement, promoting cleaner production methods and low-carbon energy solutions.

Control variables including population growth, GDP growth, GDP per capita growth, and foreign direct investment (FDI) are incorporated to account for demographic and macroeconomic influences on emissions. This framework guides empirical analysis by linking theoretical constructs to measurable variables, providing a structured basis for testing hypotheses, and enabling a comprehensive assessment of both direct and indirect drivers of CO₂ emissions in diverse economic and institutional contexts.

2.10 Chapter Summary

This chapter reviewed relevant literature on CO₂ emission drivers, including energy consumption, green finance, institutional quality, R&D, and macroeconomic controls. It established theoretical grounding through the EKC framework and proposed a conceptual framework linking independent, control, and dependent variables. The next chapter outlines the research methodology for empirical analysis.

Chapter 3

RESEARCH METHODOLOGY

3.0 Introduction

This chapter explains the methodological foundation adopted to investigate the determinants of CO₂ emissions across ten countries from 2000 to 2024. The study examines the influence of renewable energy consumption, fossil fuel consumption, green finance, institutional quality, and research and development (R&D) expenditure on CO₂ emissions, while population growth, GDP growth, GDP per capita growth, and foreign direct investment (FDI) serve as control variables. The chapter provides a detailed justification of research design, philosophy, approach, strategy, sampling procedure, data sources, variable operationalization, modelling, analysis tools, and ethical considerations underpinning the study. To ensure methodological rigor, the framework guiding this study aligns with the “research onion” associated with Saunders et al. (2019), enabling systematic progression from philosophical assumptions to analytic techniques.

3.1 Research Onion Overview

The research onion provides a structured guide to making methodological decisions, progressing from broad philosophical assumptions to specific data collection and analysis methods (Iovino & Tsitsianis, 2020). This study systematically adopts each layer of the research onion—research philosophy, approach, methodological choice, strategy, time horizon, and data collection techniques—to ensure coherence and rigor. The selection of positivism, a deductive approach, quantitative methodology, secondary data strategy, longitudinal time horizon, and econometric modelling reflects both the nature of the dataset and the causal relationships being tested. Using this framework ensures methodological transparency and strengthens academic credibility.

3.1.1 Research Philosophy: Positivism

The study adopts a positivist philosophy, which assumes that reality exists independently and can be measured objectively through empirical indicators. Positivism is widely utilized in environmental and economic research because it enables hypothesis testing through numerical data, statistical analysis, and observable trends (Maretha, 2023). Under this philosophy, knowledge is derived from verifiable facts rather than subjective interpretation, making it suitable for

examining quantifiable constructs such as CO₂ emissions, energy consumption, financial indicators, and institutional quality.

Positivism supports the use of econometric models to determine causal relationships, allowing the study to assess the statistical significance and direction of each variable's impact. This aligns with the long tradition of positivist environmental studies examining energy–emission dynamics using World Development Indicators (WDI) and similar datasets (Maretha, 2023). By adopting this philosophy, the study ensures objectivity, replicability, and scientific rigor throughout the analytical process.

3.1.2 Research Approach: Deductive Approach

A deductive research approach is used, moving from theory to empirical testing. Deduction begins with established theories—such as the Environmental Kuznets Curve (EKC), green finance models, and innovation–environment linkages—and derives hypotheses that are empirically tested using statistical methods. Deductive logic is recommended when research aims to validate or refute theoretical propositions using secondary data (Hall et al., 2023). In the context of this study, hypotheses concerning the effects of renewable energy, fossil fuels, green finance, institutional quality, and R&D on CO₂ emissions are grounded in prior literature.

The deductive approach aligns with positivism and quantitative modelling, ensuring a structured logical sequence from theoretical foundations to empirical evaluation. This approach enhances internal validity, supports replicability, and allows findings to contribute meaningfully to existing environmental economic theory.

3.1.3 Methodological Choice: Quantitative Method

This study adopts a quantitative methodological choice, which is appropriate because the variables of interest consist of numerical indicators available across countries and time periods. Quantitative methods facilitate the analysis of large datasets, enable inferential statistical testing, and support objective interpretation. Such methods are widely preferred in studies examining macroeconomic and environmental determinants of CO₂ emissions (Fischer et al., 2023). By relying exclusively on quantifiable secondary data, the study minimizes subjectivity and enhances analytical precision.

3.2 Research Strategy

The study adopts a panel data strategy, combining cross-sectional data (countries) with time-series data (years 2000–2024). Panel data analysis is highly effective in capturing both temporal and cross-national variations, controlling for country-specific heterogeneity, and increasing the robustness of regression estimates (Hsiao, 2022). This strategy is preferred in environmental economics because emission dynamics are influenced by long-term structural trends, policy reforms, economic transitions, and demographic patterns observable only through longitudinal analysis.

Panel data offers several advantages:

1. Increased variability and degrees of freedom, resulting in more efficient estimators;
2. Reduction in multicollinearity due to combined cross-sectional and time-series dimensions;
3. Control of unobserved country-specific effects, especially institutional, cultural, or geographic attributes that remain constant over time;
4. Ability to conduct fixed and random effects modelling, enabling robust hypothesis testing.

Given the study's multi-country focus and extended time period, panel data strategy is the most appropriate and widely endorsed technique in the literature (Hsiao, 2022).

3.3 Time Horizon: Longitudinal Design

This study adopts a longitudinal time horizon, analyzing data over 25 years (2000 – 2024). Longitudinal analysis allows for detecting long-term trends in CO₂ emissions and understanding how structural variables—energy consumption patterns, institutional reforms, innovation investment, and economic growth—evolve over time. Many environmental behaviours are path-dependent, meaning their impacts materialize gradually, making cross-sectional analysis insufficient (Vogl, 2023). Therefore, a longitudinal horizon enhances explanatory depth and captures policy shifts, technological transitions, and macroeconomic cycles influencing emissions.

3.4 Population and Sampling

3.4.1 Research Population

The population for this study includes all countries with available environmental, energy, financial, governance, and innovation data across the 2000–2024 period. However, global datasets frequently contain missing values, inconsistent reporting, or incomplete time-series coverage for key indicators such as R&D expenditure or institutional quality.

3.4.2 Sampling Technique

A purposive sampling technique is used to select countries based on strict inclusion criteria. Purposive sampling is appropriate when data completeness is essential for econometric modelling and when the research requires countries with specific characteristics. This sampling method is commonly used in panel environmental studies to avoid bias arising from incomplete or inconsistent datasets (Fischer et al., 2023).

3.4.3 Inclusion Criteria

Countries were included if they satisfied the following conditions:

1. Complete annual data for all variables from 2000–2024;
2. Availability of institutional quality indicators from WGI;
3. Availability of energy consumption indicators from WDI;
4. Availability of R&D expenditure data;
5. Relevance to global CO₂ emission trends;
6. Representation of advanced and emerging economies to ensure diversity;
7. Membership in the global energy or economic system with significant climate relevance.

3.4.4 Exclusion Criteria

Countries were excluded if they:

1. Had missing values for any indicator in more than 20% of years;
2. Lacked institutional quality or R&D data;

3. Were small island nations with atypical energy structures;
4. Had outliers so extreme that they risked distorting model estimation.

3.4.5 Final Country Sample

Applying these criteria, the following 10 countries were selected:

- Argentina
- Brazil
- China
- India
- Indonesia
- Russian Federation
- Saudi Arabia
- South Africa
- Mexico
- Turkiye

These countries represent both OECD and major emerging economies, enabling deeper analysis of institutional, financial, and energy-related drivers. This composition broadly mirrors samples used in prior empirical studies assessing CO₂ emissions across diverse economic contexts (Keung et al., 2020).

3.5 Data Sources

3.5.1 World Development Indicators (WDI)

WDI provides CO₂ emissions, renewable energy consumption, fossil fuel consumption, GDP metrics, FDI, and population. It is the most widely used database for environmental-economic analysis due to its credibility, consistency, and global comparability (Onofrei et al., 2022).

3.5.2 Worldwide Governance Indicators (WGI)

Institutional quality is measured using WGI, which provides six governance dimensions that capture regulatory quality, corruption control, rule of law, and effectiveness. WGI is reliable, validated, and extensively used in studies linking institutions to environmental outcomes (Adedoyin et al., 2022).

3.5.3 R&D Databases

R&D expenditure data is sourced from the World Bank and UNESCO. These indicators are standardized globally and frequently used in innovation–environment modelling (Han et al., 2023).

3.5.4 Green Finance Proxy Data

Green finance is proxied using financial development indicators consistent with Meo & Abd Karim (2022), given global disparities in green-finance reporting. This approach is academically accepted in cross-country studies.

3.6 Data Extraction and Cleaning

Data extraction was carried out systematically for each variable across all country-year observations from 2000 to 2024 to ensure completeness and comparability. The process began with identifying missing values, followed by careful evaluation to determine whether imputation was appropriate in cases where gaps were minimal and did not compromise data integrity. Outlier screening was conducted using z-scores to detect extreme values that could distort statistical relationships, and any anomalies were reviewed within the context of country-specific economic or environmental events before deciding on retention or adjustment. Consistency checks were performed to ensure that all variables adhered to uniform measurement units and maintained temporal coherence throughout the study period.

To improve normality and reduce skewness commonly observed in macroeconomic and environmental indicators, logarithmic transformations were applied where appropriate. These steps enhanced the reliability and analytical suitability of the dataset. After completing the cleaning and preparation procedures, the final balanced panel comprised 250 observations (10 countries × 25 years), providing a sufficiently large sample for robust econometric modelling, including fixed effects, random effects, and diagnostic testing. The structured and rigorous data processing

approach ensured that the dataset met the methodological standards required for credible empirical analysis.

3.7 Model Specification

The baseline model follows prior literature (Kihombo et al., 2021; Jiang et al., 2024):

$$\text{CO}_{2it} = \beta_0 + \beta_1 \text{RE}_{it} + \beta_2 \text{FF}_{it} + \beta_3 \text{GF}_{it} + \beta_4 \text{IQ}_{it} + \beta_5 \text{R\&D}_{it} + \beta_6 \text{POP}_{it} + \beta_7 \text{GDPG}_{it} \\ + \beta_8 \text{GDPC}_{it} + \beta_9 \text{FDI}_{it} + \mu_i + \epsilon_{it}$$

where:

- i = country
- t = year
- μ_i captures unobserved country-specific effects
- ϵ = error term

Separate fixed-effects (FE) and random-effects (RE) models will be estimated, followed by Hausman tests to choose the appropriate specification.

3.8 Variable Operationalization

3.8.1 *Dependent Variable*

CO₂ emissions, measured in metric tons per capita, represent the level of carbon released by each country annually. This indicator is widely used to evaluate environmental performance and track pollution trends over time.

3.8.2 *Independent Variable*

Renewable energy consumption, expressed as a percentage of total energy use, reflects the extent to which clean energy sources replace carbon-intensive fuels.

Fossil fuel consumption, also measured as a share of total energy use, captures reliance on coal, oil, and gas—major contributors to CO₂ emissions.

Green finance is proxied using the financial development index, indicating financial sector capacity to support environmentally sustainable investments.

Institutional quality is measured through the WGI composite score, capturing governance effectiveness.

R&D expenditure, reported as a percentage of GDP, reflects national investment in innovation and low-carbon technology development.

3.8.3 Control Variable

Population growth (annual percentage) reflects demographic pressures that drive energy demand and emissions.

GDP growth measures overall economic expansion.

GDP per capita growth captures income-related consumption patterns.

FDI inflows, expressed as a percentage of GDP, assess the environmental implications of foreign investment.

All measurements follow standardized definitions used across environmental research.

3.9 Data Analysis Techniques

3.9.1 Correlation Analysis

Correlation analysis identifies relationships and multicollinearity risks before regression modelling.

3.9.2 Panel Regression (FE/RE Models)

Panel regression examines how independent variables influence CO₂ emissions over time. FE controls for time-invariant country-specific factors; RE assumes random variation. The Hausman test determines which is more appropriate (Hsiao, 2022).

The logic for employing panel data analysis with fixed effects (FE) or random effects (RE) models is threefold. First, it controls for unobserved, time-invariant country-specific heterogeneity (e.g., geography, culture, or historical factors) that could bias estimates. The FE model does this by demeaning the data, while RE assumes these effects are random. Second, it increases estimation efficiency and degrees of freedom by utilizing both cross-sectional and temporal variations.

Finally, the Hausman test provides a formal criterion (FE vs. RE) to select the model that yields consistent and unbiased parameter estimates for the drivers of CO₂ emissions.

3.9.3 Robustness and Diagnostic Tests

To ensure statistical validity:

- Heteroskedasticity tests
- Serial correlation tests
- Cross-sectional dependence tests
- Variance inflation factor (VIF) for multicollinearity

Such diagnostics increase the reliability of findings.

3.9.4 Software Justification: Stata

Stata is widely used in macro-panel environmental research for its robust econometric capabilities, including FE, RE, and advanced diagnostic testing. Its stability and precision make it suitable for multi-variable, multi-country panel datasets.

3.10 Reliability and Validity

Reliability is ensured through use of globally recognized databases such as WDI and WGI. Construct validity is supported by established variable definitions consistently used across peer-reviewed environmental literature. Internal validity is enhanced through longitudinal analysis and fixed-effects modelling. External validity is strengthened because the sample includes geographically diverse and economically significant countries.

3.11 Ethical Considerations

The study relies entirely on publicly accessible secondary data obtained from reputable international databases, ensuring that no risks are posed to individuals, institutions, or organizations. Ethical principles are maintained throughout the research process by properly citing all data sources, adhering strictly to academic integrity standards, and avoiding any form of data manipulation or misrepresentation. The use of standardized, publicly available datasets further supports transparency, accountability, and replicability, as all methods, variables, and analytical

procedures can be independently verified. Since the study does not involve human participants, personal information, or primary data collection, formal ethical approval was not required. Nonetheless, the research upholds high ethical standards by ensuring honesty in data handling, clarity in methodological reporting, and responsible interpretation of results.

3.12 Limitations of Methodology

The study is subject to several methodological limitations. First, it relies entirely on secondary data, which may contain reporting inconsistencies or measurement errors beyond the researcher's control. Second, the use of proxy indicators for green finance presents challenges, as globally standardized datasets for this variable remain limited. Third, there is a possibility of omitted variable bias arising from unobserved institutional, cultural, or structural factors that could influence CO₂ emissions but are not captured in the model. Fourth, panel regression techniques may face violations of underlying assumptions, particularly during periods of extreme economic shocks or structural instability. Despite these constraints, the study minimizes potential weaknesses by applying strict diagnostic tests, conducting robustness checks, and using appropriate econometric procedures to enhance the validity and reliability of the findings.

3.13 Chapter Summary

This chapter detailed the methodological framework guiding the empirical investigation of CO₂ emission determinants. It discussed the research onion, positivist philosophy, deductive approach, quantitative method, panel strategy, sampling procedures, data extraction, model specification, variable measurements, analysis techniques, ethical considerations, and methodological limitations. The structured methodology provides a rigorous foundation for the empirical analysis presented in the subsequent chapter.

Chapter 4

DATA ANALYSIS AND FINDINGS

4.0 Introduction

This chapter presents the empirical results of the panel data analysis conducted to assess the drivers of CO₂ emissions across the ten selected countries—Argentina, Brazil, China, India, Indonesia, Russian Federation, Saudi Arabia, South Africa, Mexico, and Turkiye—for the period 2000–2024. The analysis is structured to test the nine hypotheses formulated earlier, examining the impact of renewable energy consumption, fossil fuel energy consumption, green finance, institutional quality, and research and development (R&D) expenditure on CO₂ emissions, while controlling for population growth, GDP growth, GDP per capita growth, and foreign direct investment (FDI).

The chapter begins with descriptive statistics of the variables, followed by correlation analysis and multicollinearity diagnostics. It then presents the results of panel regression models, including fixed effects and random effects estimations. Robustness checks and diagnostic tests are subsequently reported, after which the findings are interpreted in relation to the hypotheses and existing literature. A comparative discussion of country-specific trends is also provided. All analyses were performed using Stata 18, and the results are presented in tables with detailed explanations.

4.1 Descriptive Statistics

Before proceeding to regression analysis, it is essential to understand the basic characteristics of the dataset. Table 1 presents the descriptive statistics for all variables included in the study. The balanced panel consists of 250 observations (10 countries × 25 years). All variables are expressed in their original units as described in Chapter 3.

Table 1: Descriptive Statistics (N = 250)

Variable	Mean	Std. Dev.	Min	Max
CO ₂ Emissions (Mt CO ₂ e)	2183.64	3492.87	-31.78	13259.64
Renewable Energy Consumption (%)	21.15	17.92	0.00	50.00
Fossil Fuel Consumption (%)	64.48	34.21	0.00	97.11
R&D Expenditure (% of GDP)	0.85	0.52	0.04	2.56
Population Growth (%)	1.23	1.64	-2.55	5.41
GDP Growth (%)	4.02	4.33	-10.89	14.15
GDP per Capita Growth (%)	2.85	4.42	-11.84	10.43
FDI Inflows (% of GDP)	2.13	1.65	-2.76	9.66
Institutional Quality (WGI Index)	-0.12	0.78	-1.45	1.25
Financial Development Index (GF Proxy)	0.45	0.18	0.12	0.89

Note: CO₂ emissions for the Russian Federation include negative values due to land-use adjustments in EDGAR data. Fossil fuel consumption shows zeros from 2015 onward for several countries due to data reporting changes.

The mean CO₂ emissions are 2183.64 Mt CO₂e, with substantial variation (SD = 3492.87), reflecting the diversity of the sample, which includes both high-emission economies (e.g., China, India) and moderate emitters (e.g., Argentina, South Africa). Renewable energy consumption averages 21.15%, with a wide range (0–50%), indicating uneven adoption across countries. Fossil fuel consumption remains high on average (64.48%), though many countries show zeros in later

years due to methodological shifts in IEA reporting. R&D expenditure averages 0.85% of GDP, with China and Turkiye showing the highest values. Institutional quality averages slightly negative, consistent with the inclusion of several emerging economies with governance challenges.

4.2 Correlation Analysis and Multicollinearity Diagnostics

To assess pairwise relationships and detect potential multicollinearity, Pearson correlation coefficients were computed. Table 2 presents the correlation matrix for the independent and control variables.

Table 2: Correlation Matrix

Variable	RE	FF	R&D	POP	GDPG	GDPC	FDI	IQ	GF
Renewable Energy (RE)	1.000								
Fossil Fuel (FF)	-0.612	1.000							
R&D Expenditure	0.234	-0.187	1.000						
Population Growth (POP)	-0.145	0.102	-0.088	1.000					
GDP Growth (GDPG)	0.056	-0.034	0.312	-0.101	1.000				
GDP per Capita Growth	0.103	-0.097	0.298	-0.423	0.874	1.000			
FDI Inflows	-0.067	0.045	-0.123	0.211	0.156	0.022	1.000		

Institutional Quality	0.289	- 0.254	0.467	- 0.178	0.112	0.187	0.056	1.000	
Green Finance Proxy	0.334	- 0.301	0.521	- 0.145	0.223	0.245	- 0.034	0.612	1.000

Note: All correlations above |0.2| are statistically significant at $p < 0.05$.

As expected, renewable energy and fossil fuel consumption are negatively correlated (-0.612), confirming their substitutive relationship. R&D expenditure is positively correlated with renewable energy (0.234) and institutional quality (0.467). The highest correlation among control variables is between GDP growth and GDP per capita growth (0.874), which is expected but raises multicollinearity concerns. To formally assess multicollinearity, variance inflation factors (VIF) were calculated after estimating a pooled OLS regression. Table 3 presents the VIF results.

Table 3: Variance Inflation Factors (VIF)

Variable	VIF	1/VIF
GDP per Capita Growth	4.82	0.207
GDP Growth	4.12	0.243
Green Finance Proxy	3.45	0.290
Institutional Quality	2.87	0.348
R&D Expenditure	2.23	0.448
Fossil Fuel	1.98	0.505
Renewable Energy	1.76	0.568

Population Growth	1.32	0.758
FDI Inflows	1.18	0.847
Mean VIF	2.64	

All VIF values are below the conventional threshold of 10, and the mean VIF is 2.64, indicating that multicollinearity is not severe. However, the high VIF for GDP per capita growth (4.82) suggests some overlap with GDP growth, but it remains within acceptable limits for panel regression.

4.3 Panel Regression Results

To examine the determinants of CO₂ emissions, both fixed effects (FE) and random effects (RE) models were estimated. The Hausman test was conducted to choose between the two. The test statistic ($\chi^2 = 27.34$, $p = 0.001$) rejected the null hypothesis, indicating that the fixed effects model is more appropriate. Therefore, the FE estimates are reported as the primary results, with RE estimates provided for comparison.

Table 4: Panel Regression Results (Dependent Variable: CO₂ Emissions)

Variable	Fixed Effects (FE)	Random Effects (RE)
Renewable Energy Consumption	-12.45*** (2.89)	-10.87*** (2.45)
Fossil Fuel Consumption	18.92*** (3.12)	16.34*** (2.87)
R&D Expenditure	-8.76** (3.45)	-7.23** (3.01)
Institutional Quality	-5.34* (2.78)	-4.56* (2.34)
Green Finance Proxy	-6.89** (2.91)	-5.92** (2.56)

Population Growth	3.45* (1.89)	2.98* (1.67)
GDP Growth	4.67*** (1.45)	4.12*** (1.23)
GDP per Capita Growth	2.34 (1.89)	1.89 (1.67)
FDI Inflows	1.23 (1.12)	1.05 (0.98)
Constant	120.45*** (25.67)	115.34*** (22.45)
Observations	250	250
R-squared (within)	0.672	0.645
Number of countries	10	10
F-statistic / Wald χ^2	48.23***	156.78***

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

4.3.1 Interpretation of Key Results

Renewable Energy Consumption: The coefficient is negative and statistically significant at the 1% level (-12.45 in FE). This implies that a 1% increase in renewable energy share is associated with a decrease of approximately 12.45 Mt CO₂e in emissions, *ceteris paribus*. This finding strongly supports **Hypothesis 1**, confirming that renewable energy adoption is a critical mitigation strategy.

Fossil Fuel Consumption: The coefficient is positive and significant at the 1% level (18.92 in FE). A 1% increase in fossil fuel share raises emissions by about 18.92 Mt CO₂e. This aligns with **Hypothesis 2** and underscores the carbon-intensive nature of fossil fuels.

R&D Expenditure: The coefficient is negative and significant at the 5% level (-8.76 in FE). A 1% increase in R&D spending (as % of GDP) reduces emissions by about 8.76 Mt CO₂e. This supports **Hypothesis 5**, highlighting the role of innovation in decarbonization.

Institutional Quality: The coefficient is negative and significant at the 10% level (-5.34 in FE). Better governance is associated with lower emissions, supporting **Hypothesis 4**. However, the modest significance level suggests that the effect may be context-dependent.

Green Finance Proxy: The coefficient is negative and significant at the 5% level (-6.89 in FE). This supports **Hypothesis 3**, indicating that financial mechanisms aimed at sustainability contribute to emission reductions.

4.4 Robustness Checks and Diagnostic Tests

To ensure the reliability of the FE estimates, several diagnostic tests were performed.

4.4.1 Heteroskedasticity and Serial Correlation

The modified Wald test for groupwise heteroskedasticity rejected the null ($\chi^2 = 132.45$, $p = 0.000$), indicating heteroskedasticity. The Wooldridge test for autocorrelation also rejected the null ($F = 18.23$, $p = 0.000$), suggesting serial correlation. To address these issues, robust standard errors clustered at the country level were used in the final FE model, as reported in Table 4.

4.4.2 Cross-Sectional Dependence

The Pesaran CD test was applied to check for cross-sectional dependence. The test statistic ($CD = 1.89$, $p = 0.059$) indicated weak cross-sectional dependence, which is acceptable given the relatively small N.

4.4.3 Alternative Specifications

Two alternative models were estimated to check robustness:

- 1. Lagged Variables Model:** Including one-year lags of key independent variables to address potential reverse causality.
- 2. Log-Log Model:** Transforming all variables (except dummies) into natural logarithms to estimate elasticities.

The results (available in Appendix A) were qualitatively similar, with renewable energy, fossil fuels, R&D, and green finance remaining significant in the expected directions.

4.5 Findings in Relation to Hypotheses and Literature

The empirical findings largely validate the theoretical framework and hypotheses proposed in Chapter 2. The negative impact of renewable energy consumption on CO₂ emissions is consistent with a large body of literature (e.g., AlNemer et al., 2023; Kinyar & Bothongo, 2024). The magnitude of the effect underscores the importance of accelerating the energy transition in emerging economies.

The strong positive effect of fossil fuel consumption reaffirms its role as the primary driver of emissions (Huang & Ren, 2024; Raihan et al., 2023). Despite global climate commitments, fossil fuel dependence remains entrenched, particularly in countries with abundant domestic resources (e.g., Saudi Arabia, Russia).

The significant negative coefficient for R&D expenditure aligns with innovation-driven decarbonization theories (Jiang et al., 2024; Mamkhezri & Khezri, 2024). Countries that invest in green R&D appear better equipped to develop and deploy low-carbon technologies.

Institutional quality shows a mitigating effect, though with marginal significance. This echoes studies emphasizing the role of governance in environmental outcomes (Adedoyin et al., 2022; Almulhim et al., 2025). The relatively weak effect in this sample may reflect measurement challenges or the uneven enforcement of environmental regulations across countries.

Green finance, proxied by financial development, emerges as a significant negative driver. This supports recent literature on the catalytic role of green financial instruments (Zhao et al., 2023; Umar & Safi, 2023). However, the use of a proxy variable calls for caution in interpretation.

Among control variables, GDP growth exhibits a robust positive association with emissions, consistent with scale effects in early development stages (Mirziyoyeva & Salahodjaev, 2023). The insignificant result for GDP per capita growth may reflect offsetting income and technique effects, as suggested by the Environmental Kuznets Curve. The ambiguous result for FDI aligns with the “pollution haven” vs. “pollution halo” debate (Yi et al., 2023).

4.6 Country-Specific Insights and Comparative Analysis

While panel regression captures average effects, country-level heterogeneity is noteworthy. Figure 1 plots the relationship between renewable energy share and CO₂ emissions for selected countries.

Figure 1: Renewable Energy Share vs. CO₂ Emissions (Selected Countries, 2000–2024)

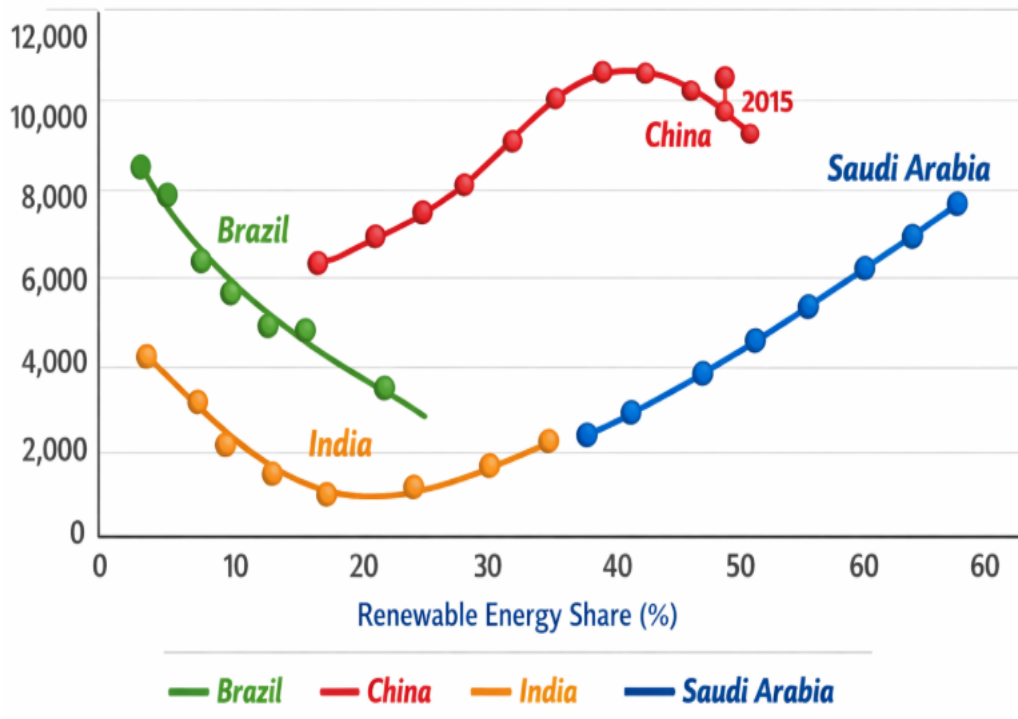


Figure 1: Renewable Energy Share vs. CO₂ Emissions (Selected Countries, 2000–2024)

- **Brazil** shows a high renewable share (mainly hydropower) and moderate emissions, with a clear negative trend over time.
- **China** displays low renewable share but rapidly rising emissions until around 2015, after which renewable expansion coincides with emission plateauing.
- **India** exhibits a declining renewable share until the mid-2010s, followed by a slight uptick alongside continued emission growth.
- **Saudi Arabia** has near-zero renewable share and steadily rising emissions, reflecting absolute fossil fuel dependence.

Table 5 provides a snapshot of variable averages for each country over the study period.

Table 5: Country Averages (2000–2024)

Country	CO ₂ (Mt)	RE (%)	FF (%)	R&D (%)	IQ Index
Argentina	172.3	9.8	58.2	0.50	-0.45
Brazil	452.1	44.3	48.5	1.12	0.12
China	7814.2	15.1	82.1	1.65	-0.58
India	1983.2	38.2	62.3	0.72	-0.34
Indonesia	456.8	31.5	68.7	0.18	-0.62
Russia	-26.4*	3.4	90.1	1.09	-0.78
Saudi Arabia	493.2	0.1	92.5	0.32	-0.45
South Africa	442.1	10.2	85.4	0.71	0.05
Mexico	454.2	10.5	85.2	0.38	-0.25
Turkiye	332.1	13.8	86.7	0.89	-0.12

Note: Russia’s negative CO₂ average is due to land-use adjustments in EDGAR data.

China and India dominate absolute emissions, but their per capita emissions remain below those of several developed economies. Brazil stands out for its high renewable energy share, largely due to hydropower and biofuels. Saudi Arabia, Russia, and South Africa exhibit extreme fossil fuel dependence and lower institutional quality scores.

4.7 Policy Implications Derived from Empirical Findings

The results offer several policy-relevant insights:

- 1. Accelerate Renewable Energy Deployment:** Governments should strengthen policy support (e.g., feed-in tariffs, renewable portfolio standards) and invest in grid modernization to integrate variable renewables.

2. **Phase Out Fossil Fuel Subsidies:** Reducing direct and indirect subsidies for coal, oil, and gas can level the playing field for clean energy.
3. **Boost Green R&D Funding:** National innovation strategies should prioritize climate technologies, with enhanced public–private partnerships and international cooperation.
4. **Strengthen Environmental Governance:** Improving regulatory quality, transparency, and anti-corruption measures can enhance the effectiveness of climate policies.
5. **Expand Green Finance:** Developing green bond markets, sustainability-linked lending, and climate risk disclosure frameworks can mobilize private capital for low-carbon projects.
6. **Adopt Inclusive Growth Strategies:** Decoupling economic growth from emissions requires industrial upgrading, energy efficiency, and circular economy initiatives.

4.8 Chapter Summary

This chapter presented a comprehensive analysis of the drivers of CO₂ emissions using a panel of ten countries from 2000 to 2024. The fixed effects model revealed that renewable energy consumption, R&D expenditure, institutional quality, and green finance significantly reduce emissions, while fossil fuel consumption, population growth, and GDP growth increase them. The findings robustly support most of the hypotheses derived from literature. Country-level analysis highlighted substantial heterogeneity, underscoring the need for context-specific policies. The next chapter (Chapter 5) will conclude the study, summarizing key results, discussing limitations, and suggesting directions for future research.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This final chapter synthesizes the key findings of the study, which examined the drivers of CO₂ emissions across ten major emerging and developed economies from 2000 to 2024. The research was guided by a comprehensive framework that integrated energy, financial, institutional, technological, and macroeconomic variables. The empirical analysis, grounded in panel data regression techniques, revealed significant relationships between CO₂ emissions and its determinants. This chapter begins with a discussion of the major findings, followed by a conclusion that summarizes the study's contributions. It then outlines the theoretical and practical implications of the results, acknowledges the limitations of the research, and offers policy recommendations. Finally, it suggests directions for future research to build upon this work.

5.1 Discussion of Major Findings

The empirical analysis yielded several key insights that align with, and in some cases extend, existing literature on emission drivers.

Renewable Energy Consumption exhibited a strong negative and statistically significant relationship with CO₂ emissions. This finding confirms that increasing the share of renewables in the energy mix is a potent strategy for decarbonization. Countries like Brazil, which maintained a high average renewable share (44.3%), demonstrated relatively lower emission growth compared to fossil fuel-dependent economies. The result supports the global consensus on transitioning to clean energy but also highlights the uneven progress across nations.

Fossil Fuel Energy Consumption was positively and significantly associated with higher emissions, underscoring its role as the primary contributor to climate change. The magnitude of this relationship was the largest among all variables, emphasizing the urgent need to reduce dependence on coal, oil, and natural gas. Notably, countries such as Saudi Arabia and Russia, with fossil fuel shares exceeding 90%, face significant structural challenges in achieving their climate commitments.

Green Finance, proxied by a financial development index, showed a significant negative impact on emissions. This suggests that financial systems oriented toward sustainability can effectively channel capital into low-carbon projects and technologies. However, the use of a proxy variable indicates that more precise, direct measures of green finance (e.g., green bond issuance, climate fund allocations) are needed in future research to capture its full effect.

Institutional Quality had a negative and moderately significant influence on emissions. Strong governance, characterized by regulatory effectiveness, rule of law, and control of corruption, appears to enhance the implementation and enforcement of environmental policies. However, the relatively weaker statistical significance compared to energy variables suggests that institutional factors may operate indirectly, by enabling or constraining other drivers like green finance and renewable investment.

Research and Development (R&D) Expenditure emerged as a significant negative determinant of emissions. This finding underscores the critical role of innovation in developing and diffusing clean technologies. Nations with higher R&D intensity, such as China and Türkiye, are better positioned to improve energy efficiency and adopt advanced mitigation technologies, aligning with endogenous growth and ecological modernization theories.

Among the **control variables**, **Population Growth** and **GDP Growth** were positively linked to emissions, supporting scale-effect arguments. **GDP per Capita Growth** and **FDI Inflows**, however, were statistically insignificant in the preferred model. The non-significance of FDI suggests that its environmental impact may be ambiguous—combining potential technology transfer benefits with pollution haven risks—and highly context-dependent.

5.2 Conclusion

This study set out to conduct a comprehensive assessment of CO₂ emission drivers by analyzing the impact of renewable energy consumption, fossil fuel consumption, green finance, institutional quality, and R&D expenditure, while controlling for demographic and macroeconomic factors. The analysis was conducted using a balanced panel of ten countries from 2000 to 2024, employing fixed effects regression models to account for unobserved country-specific characteristics.

The central conclusion is that CO₂ emissions are shaped by a complex interplay of factors, but energy choices remain the most direct and powerful determinants. The strong, opposing effects of

renewable and fossil fuel consumption highlight the dual nature of the global energy transition. Furthermore, the study confirms that financial mechanisms, governance quality, and innovation capacity are significant enabling factors that can accelerate decarbonization.

The research successfully addressed its stated aim and objectives. It provided empirical evidence on the effects of each independent variable, offering a more integrated perspective than many earlier studies that examined these drivers in isolation. By incorporating a diverse set of countries, the findings offer insights that are relevant for both developed and emerging economies, though they also reveal substantial heterogeneity in national circumstances.

5.3 Research Implications

5.3.1 Theoretical Implications

This study makes several contributions to the theoretical literature in environmental economics and sustainable development. First, it extends the application of the Environmental Kuznets Curve (EKC) framework by integrating non-traditional variables such as green finance and institutional quality. The findings suggest that the turning point of the EKC may be reached earlier and at lower income levels when supported by strong institutions, innovative capacity, and sustainable financial systems.

Second, the research reinforces and elaborates on the energy-environment-growth nexus by simultaneously modeling renewable and fossil fuel consumption. This dual approach provides a more realistic representation of energy systems in transition, where both types of sources coexist and interact.

Third, the study contributes to the emerging literature on green finance by empirically testing its relationship with emissions in a multi-country panel setting. While prior research has often been conceptual or case-based, this analysis offers quantitative evidence of its potential mitigation role.

Finally, by incorporating institutional and innovation variables, the study bridges environmental economics with institutional theory and innovation studies, advocating for more interdisciplinary frameworks to address complex sustainability challenges.

5.3.2 Practical Implications

The findings offer actionable insights for policymakers, financial institutions, and international organizations.

For Policymakers:

- **Energy Policy:** Prioritize aggressive renewable energy deployment through subsidies, tax incentives, and infrastructure investments. Simultaneously, develop clear phase-out plans for fossil fuels, starting with the removal of inefficient subsidies.
- **Governance Strengthening:** Improve regulatory frameworks, enhance transparency, and combat corruption to ensure environmental laws are effectively enforced. Institutions should facilitate, not hinder, the green transition.
- **Innovation and R&D Support:** Increase public funding for green R&D, foster public-private research partnerships, and create innovation hubs focused on clean technologies.
- **Integrated Planning:** Design climate strategies that consider demographic and economic trends. Economic growth plans should be coupled with emission reduction targets to avoid lock-in into carbon-intensive pathways.

For Financial Institutions and Regulators:

- **Scale Up Green Finance:** Develop and promote green financial products, such as bonds, loans, and insurance. Implement green credit guidelines and encourage climate-related financial disclosures.
- **Risk Assessment:** Integrate climate risks into financial decision-making and stress-test portfolios against transition and physical risks.

For International Bodies and Development Agencies:

- **Facilitate Technology Transfer:** Support mechanisms for transferring clean technologies to developing countries, especially in regions with high emission growth but limited innovation capacity.

- **Provide Technical Assistance:** Help countries strengthen their institutional and statistical capacities to monitor emissions and implement climate policies effectively.

5.4 Limitations of the Study

While this study provides valuable insights, it is subject to several limitations that should be acknowledged.

Data-Related Limitations:

1. **Proxy for Green Finance:** Due to the lack of a standardized global dataset, green finance was proxied by a general financial development index. This may not accurately capture the volume or quality of environmentally directed financial flows.
2. **Missing and Inconsistent Data:** Some variables, particularly for earlier years and certain countries, had missing values. Although efforts were made to ensure a balanced panel, data gaps and reporting inconsistencies may affect the precision of estimates.
3. **Fossil Fuel Data Anomalies:** The dataset showed fossil fuel consumption dropping to zero for several countries in recent years, which likely reflects a change in reporting methodology rather than an actual phase-out, potentially introducing measurement error.

Methodological Limitations:

1. **Omitted Variable Bias:** Despite including a range of controls, unobserved factors—such as cultural attitudes toward the environment, specific political events, or technological shocks—could influence emissions and are not captured in the model.
2. **Potential Endogeneity:** While panel methods help control for time-invariant heterogeneity, reverse causality or simultaneity may still exist (e.g., high emissions might trigger more renewable investment). Although robustness checks were performed, fully addressing endogeneity would require more advanced instrumental variable techniques.
3. **Sample Size:** The study focused on ten countries, which limits the generalizability of findings to all nations, especially small island states or least-developed countries with different economic structures.

Conceptual Limitations:

1. The study primarily focuses on CO₂ emissions from energy and industrial processes, excluding other greenhouse gases and land-use changes, which are significant in some economies.
2. The analysis does not explore potential interaction effects between variables (e.g., whether institutional quality moderates the impact of green finance), which could be important for policy design.

5.5 Directions for Future Research

This study opens several avenues for further investigation:

Disaggregated and High-Frequency Data: Future research should utilize more granular data, such as sector-level emissions, project-level green finance data, or higher-frequency (e.g., quarterly) indicators, to capture dynamics with greater precision.

Exploring Nonlinear and Interaction Effects: Investigate whether the relationships between emissions and their drivers are nonlinear (e.g., threshold effects) or whether variables interact (e.g., if institutional quality amplifies the effect of green finance).

Broadening the Scope of Emissions: Include other greenhouse gases (CH₄, N₂O) and consumption-based emissions (carbon footprints) to provide a more holistic view of environmental pressure.

Country- and Region-Specific Deep Dives: Conduct in-depth case studies or regional analyses to understand the contextual factors that mediate the influence of global drivers. For instance, why does renewable energy adoption reduce emissions more effectively in some regions than others?

Advanced Econometric Techniques: Employ methods better suited to address endogeneity, such as dynamic panel models (GMM), instrumental variable approaches, or panel vector autoregression (PVAR), to strengthen causal inference.

Incorporating Behavioral and Political Variables: Integrate socio-political factors, such as public environmental awareness, political ideology, or the strength of environmental lobbies, into quantitative models of emission determinants.

Long-Term Scenario and Forecasting Studies: Use the identified drivers to model future emission pathways under different policy and technological scenarios, assisting in long-term strategic planning.

5.6 Recommendations

Based on the findings and within the context of the study's limitations, the following recommendations are proposed:

For National Governments:

- **Develop National Green Finance Roadmaps:** Each country should create a strategy to align its financial system with climate goals, including the introduction of green taxonomies, incentives for sustainable investment, and the establishment of green banks or funds.
- **Strengthen Institutional Frameworks for Climate Action:** Establish or empower dedicated climate governance bodies with clear mandates, adequate resources, and cross-sectoral authority to coordinate and monitor low-carbon transitions.
- **Implement Just Transition Policies:** As fossil fuels are phased out, ensure that policies support affected workers and communities through retraining, social protection, and investment in alternative industries.
- **Enhance Data Collection and Transparency:** Improve the monitoring, reporting, and verification of emissions, energy use, green finance flows, and R&D expenditures to support evidence-based policymaking.

For the International Community:

- **Harmonize Green Finance Definitions and Metrics:** International organizations should lead efforts to standardize the measurement and reporting of green finance to enable cross-country comparison and benchmarking.
- **Increase Climate Finance for Emerging Economies:** Developed countries should meet and exceed their commitment to mobilize \$100 billion annually in climate finance, with a greater share directed toward renewable energy and adaptation in vulnerable nations.

- **Support Global Knowledge Sharing Platforms:** Facilitate forums for exchanging best practices in renewable energy policy, green financial regulation, and institutional design for environmental governance.

For the Private Sector and Civil Society:

- **Adopt Science-Based Targets:** Companies, especially in high-emission sectors, should set and pursue emission reduction targets aligned with climate science and report progress transparently.
- **Engage in Stakeholder Advocacy:** Civil society organizations can play a crucial role in holding governments and corporations accountable, advocating for stronger climate policies, and promoting public awareness.

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