IBN HALDUN UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF MANAGEMENT

MASTER'S THESIS

THE EFFECT OF INNOVATION ON CO2 EMISSIONS IN EMERGING MARKETS

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THESIS SUPERVISOR

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THE EFFECT OF INNOVATION ON CO2 EMISSIONS IN EMERGING MARKETS

by
IBRAHIM MOHAMMED BAGUE

A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Arts (MA) in Management

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This thesis has been read by us, and it has been decided that it is sufficient in terms of scope and quality to obtain a master's degree in the field of Management.

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ÖZ

GELİŞMEKTE OLAN PAZARLARDA İNOVASYONUN CO2 EMİSYONU ÜZERİNDEKİ ETKİSİ

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Araştırma, inovasyonun gelişmekte olan piyasalarda CO2 emisyonu üzerindeki etkisini araştırmayı amaçlamıştır. Çalışma, gelişmekte olan piyasalarda inovasyon ve CO2 emisyonları arasındaki ilişkiyi incelemiş ve inovasyonun Çevresel Kuznets Eğrisi'nin (EKC) varlığını incelemiştir. Çalışmada kullanılan araştırma tasarımı açıklayıcı ve nicel bir çalışmadır. Araştırma, S&P Dow Jones endeksleri tarafından sınıflandırılan gelişmekte olan piyasaları dikkate almıştır. Bu endekse göre toplam 23 gelişmekte olan piyasa bulunmaktadır. Veri mevcudiyeti nedeniyle çalışma için 15 ülke örneklemi kullanılmıştır. Bu araştırmada esas olarak 15 ülkenin her birine ilişkin Dünya Kalkınma Göstergeleri (WDI) veri tabanından elde edilen ikincil veriler kullanılmıştır. Çalışmada modeli tahmin etmek için panel veri kullanılmış olup, ülkeler arasındaki ve zaman içindeki değişimleri ele almak için zaman serisi ve yatay kesit verilerinden oluşmaktadır. Ampirik ilişkiler sabit etkiler modeli kullanılarak analiz edilmiştir. Çalışma, inovasyon ve CO2 emisyonu arasındaki ilişkinin negatif bir sonuç verdiğini ortaya koymuştur; bu da inovasyondaki ilerlemenin CO2 emisyonunda bir azalmaya yol açtığı anlamına gelmektedir. İnovasyon Çevresel Kuznets Eğrisinin varlığını tespit etmek için inovasyonun karesi alındıktan sonra, sonuçlar inovasyona yapılan yatırımın ters “U” şeklinde bir eğriye yol açmadığını, dolayısıyla emisyonlarda bir azalmaya yol açtığını, ancak belirli bir eşikten sonra daha fazla yatırımın azalan getirilerle sonuçlanabileceğini göstermektedir.

Anahtar Kelimeler: CO2 Emisyonu, Çevresel Kuznets Eğrisi, Sabit Etki Modeli.

ABSTRACT

THE EFFECT OF INNOVATION ON CO_2 EMISSION IN EMERGING MARKETS

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The research sought to investigate the effect innovation has on CO2 emission in emerging markets. The study examined the relationship between innovation and CO2 emissions in emerging markets and examined the presence of innovation Environmental Kuznets Curve (EKC). The research design employed in the study was an explanatory and quantitative study. The research considered the emerging markets as classified by the S&P Dow Jones indices. There are a total of 23 emerging markets according to this index. The sample of 15 countries were used for the study due to data availability. This research mainly used secondary data from the World Development Indicators (WDI) database respective to each of the 15 countries. The study used a panel data to estimate the model, which comprises of time series and cross-sectional data to deal with variations across countries and over time. The empirical relations were analysed using the fixed effects model. The study found that the relationship between innovation and CO2 emission yielded a negative result which implies that advancement in innovation leads to a reduction in CO2 emission. After squaring innovation to establish the presence of innovation Environmental Kuznets Curve, the results shows that investment in innovation does not lead to an inverted “U” shaped curve, thus it leads to a reduction in emissions however after a certain threshold, further investments may result in diminishing returns.

Keywords: CO2 Emission, Environmental Kuznets Curve, Fixed Effect Model.

DEDICATION

I dedicate this thesis work to my family, friends, and loved ones, and to the entire Ibn Haldun University community.

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My profound gratitude goes to Dr. Merve Şahin for his tremendous support, continued encouragement, and confidence in me. I would also like to thank all the professors in the MA. Management Department for their unflinching support throughout my master's studies at Ibn Haldun University.

Ibrahim Mohammed BAGUE

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CHAPTER I

INTRODUCTION

1.1. Background of the Study

The link between innovation and environmental sustainability has acquired significant attention in recent years, particularly as emerging markets grapple with the challenge of balancing rapid economic growth with the urgent need to address environmental degradation. As these economies industrialize at an accelerating pace, they inevitably contribute to a rise in CO2 emissions, further exacerbating global climate change. Despite the growing significance of this issue, the exact role that innovation can play in reducing emissions within these markets remains underexplored. This research proposal aims to delve into how innovation impacts CO2 emissions in emerging markets, with a focus on technological advancements, green innovation, and policy-driven initiatives that shape the carbon footprint of these regions.

The change in climate is undoubtedly One of the most vital globally concerns, and emerging markets, with their rapid industrialization and increasing energy demands, sit at the epicenter of this issue. While these economies are vital contributors to global CO2 emissions, they also present a unique opportunity. Innovation especially in the form of new technologies, green solutions, and policy reforms has the potential to mitigate the environmental harm caused by industrial expansion. By embracing cutting-edge advancements and sustainable practices, emerging markets can significantly reduce Their carbon footprints and contributions to global efforts to address climate change.

Countries like China, India, Brazil, and South Africa are particularly well-positioned to lead this charge. As major industrial hubs, they have already become key players in the global economy. Yet, unlike their developed counterparts, they have the chance to bypass outdated, polluting technologies in favor of innovative solutions that promote environmental sustainability. The proposed study seeks to examine how various forms of innovation whether technological, green, or policy-driven can influence CO_2 emissions in these markets. By providing empirical evidence and policy recommendations, the research will offer valuable insights on how emerging economies can foster sustainable growth while addressing their environmental challenges.

Emerging markets are facing an urgent dilemma as they race toward economic growth while also grappling with the environmental consequences of industrialization. These economies are expanding at a rapid pace, driven by urbanization and industrialization, but this progress is accompanied by a sharp rise in CO_2 emissions. In this context, innovation particularly in the realm of green technologies emerges as a vital solution. Through technological advancements, such as renewable energy sources, energy-efficient manufacturing practices, and sustainable production methods, emerging markets can decouple economic growth from environmental degradation.

Proactive green innovation, which focuses on boosting resource efficiency and reducing waste, offers a dual benefit: it significantly lowers CO_2 emissions and improves the financial performance of businesses (Johl & Toha, 2021). Innovations like sustainable energy solutions, efficient manufacturing technologies, and energy-saving devices are essential for mitigating the environmental costs associated with industrial expansion, especially in emerging economies (Johl & Toha, 2021). Furthermore, technological developments in sectors like energy and transportation are pivotal in lowering the carbon footprint of these economies. By increasing energy efficiency and embracing clean technologies, these markets can reduce their dependence on polluting industries, fostering a shift toward more sustainable development pathways (Boggia et al., 2021).

In addition to technological innovations, a well-functioning financial system plays a crucial role in accelerating the adoption of green technologies. Access to capital enables the scaling up of clean technologies, which helps achieve substantial environmental gains while supporting continued economic growth (Boggia et al., 2021). Furthermore, green innovations are not just about environmental benefits they are intrinsically linked to economic growth. As emerging markets adopt greener practices, they are not only reducing their ecological impact but also enhancing their long-term economic resilience and competitiveness (Huan & Qamruzzaman, 2022).

A further driving force is the digital transformation of industries. By embracing digital tools, industries in emerging markets can adopt cleaner, more efficient technologies that help reduce CO_2 emissions while increasing productivity and profitability (Huan & Qamruzzaman, 2022). Regulatory pressures are also pushing businesses toward more eco-friendly practices, creating a strong incentive to integrate sustainability into their operations. The combined effect of technological innovation, financial support, and regulatory frameworks presents a powerful opportunity for emerging markets to tackle environmental challenges while securing long-term economic growth and stability.

Emerging markets are at a critical juncture, experiencing rapid industrialization and economic growth while simultaneously struggling with the environmental consequences of rising CO_2 emissions. The role of innovation, especially in the development of green and low-carbon technologies, is becoming increasingly essential in addressing this dilemma. Technological and scientific advancements in energy production, manufacturing, and transportation have been shown to significantly reduce carbon emissions, offering a pathway for these economies to achieve both growth and environmental sustainability (Lou et al., 2022). Green innovations ranging from renewable energy technologies to more efficient industrial processes offer cost-effective solutions that can substantially curb CO_2 emissions while spurring economic progress ((Afrifa et al., 2020); Yuan, 2021).

For example, the implementation of cleaner technologies in sectors like manufacturing and energy has demonstrated the possibility of decoupling economic growth from environmental harm, allowing emerging markets to pursue sustainable development that is both economically and environmentally viable (Yuan, 2021). Furthermore, the spatial dynamics of innovation where regions with better access to technological advancements tend to show lower emissions underscore the importance of innovation in mitigating the environmental impact of industrialization in emerging economies (Lou et al., 2022).

In addition to cleaner energy and manufacturing technologies, innovations like electric vehicles, energy-efficient appliances, and smart infrastructure play a direct role in reducing the carbon footprints of industrial sectors (Afrifa et al., 2020). These innovations not only benefit the environment but also foster economic growth by improving productivity and reducing operational costs. As financial systems and policies adapt to support the scaling of green technologies, emerging markets stand to benefit from a more sustainable and economically resilient future. Ultimately, innovations in both technology and finance hold immense potential to reduce CO2 emissions and guide these economies toward a greener, more prosperous future (Yuan, 2021; (Lou et al., 2022).

In essence, innovation is the key to reducing CO2 emissions and fostering a more sustainable economic future in emerging markets. This intersection of technology, finance, and policy not only supports environmental goals but also helps these economies build resilience in an increasingly competitive and eco-conscious global market.

1.2. Problem Statement

Research on the impact of innovation on CO2 emissions in emerging markets presents a mixed picture. Some studies indicate a negative correlation between innovation input and CO2 emissions, suggesting that innovation can indeed help tackle climate change (Afrifa et al., 2020). However, the effects seem to vary across different sectors and regions. For example, in China, innovations in alternative energy production, such as raw coal and crude oil, have been shown to reduce emissions. On the other hand, innovations related to natural gas seem to increase emissions (Shen et al., 2023). Similarly, in G20 countries, innovations within the industrial sector contribute to emission reductions, while innovations in construction often have the opposite effect, raising emissions (Erdoğan et al., 2020). In BRICS countries, technological innovations related to the environment have had a positive impact on energy productivity and CO_2 reduction (Santra, 2017).

Moreover, governance factors, including political stability and the control of corruption, seem to influence how innovations affect emissions. This suggests that the effectiveness of innovation in reducing emissions is not just about the technology itself but also about the political and institutional context in which it is applied (Afrifa et al., 2020). These findings underscore the complex and multifaceted nature of the relationship between innovation and CO_2 emissions in emerging markets, where sector-specific dynamics and governance factors play a significant role in determining the outcomes.

Emerging markets are caught in a delicate balancing act: driving economic growth while tackling the environmental challenges, particularly the reduction of carbon dioxide (CO_2) emissions. As these economies industrialize and urbanize, their dependence on carbon-heavy energy sources and manufacturing methods continues to rise, deepening the global climate crisis. At the same time, green technologies have emerged as a crucial solution to this dilemma, offering hope for mitigating emissions. However, the relationship between innovation especially in environmental technologies and CO_2 reduction remains under-explored. Research on this topic presents conflicting findings across different regions and contexts. While some studies suggest that innovations in renewable energy and energy-efficient technologies can significantly lower carbon footprints (Huang et al., 2022), others argue that these innovations alone may fall short without the backing of strong policy frameworks and adequate financial support (Afrifa et al., 2020).

The Environmental Kuznets Curve (EKC) hypothesis also comes into play here. It suggests that while economic growth initially leads to higher emissions, over time, as economies mature and greener technologies are adopted, emissions tend to decrease. However, there’s no clear consensus on how well this theory applies to emerging markets (Xiaoyang et al., 2022a). Despite increasing investments in green technologies, many emerging markets still struggle with high energy intensity, and the effects of economic policy uncertainty on energy innovation remain largely unexplored (Zhao et al., 2020). This study aims to delve into how innovations particularly in green and low-carbon technologies can effectively reduce CO_2 emissions in emerging markets. It will consider the role of policy, economic growth, and regional disparities to better understand how these innovations contribute to both economic and environmental sustainability. Understanding these dynamics is essential for shaping policies that can truly foster sustainable development in emerging economies.

1.3. Research Objectives

This research aims to discuss the effect of innovation on CO_2 emission in Emerging Markets. The study will specifically address the following objectives:

i. To assess the relationship between CO_2 emission and innovation

H1: Innovation has a significant effect on CO_2 emission in Emerging Markets

ii. To test for the presence of innovation in Environment Kuznets Curve (EKC)

H2: Innovation Environment Kuznets Curve (EKC) exist in Emerging Markets

1.4. Research Questions

i. What is the relationship between innovation and CO_2 emission?
ii. Does Innovation Environment Kuznets Curve (EKC) exist in Emerging Markets?

1.5. Significance of the Study

This research will provide critical insights into how innovation contributes to the emission of CO_2 gasses in growing economies. It will also give insights as to whether innovation contributes to the reduction of CO_2 emissions in emerging markets. Given that these markets are projected to account for the majority of future global economic growth and emissions, understanding the role of innovation is vital for global environmental sustainability. This research will help raise more lofty issues on climate change and innovation as identified as a major potential to improve climate change mitigation in emerging markets. This research will help raise additional topics to be examined in climate change initiatives since it is a field that has been identified as having a significant potential to influence the causes of climate change.

1.6. Scope and Limitation of the Study

The scope of the research was limited to emerging markets to ascertain the effect of innovation on growing economies. Some limitations of the research work included combining work and socio-culture activities was a challenge in carrying out thus research work. Since the study will be using secondary data, cost of data collection, time and financial resource is expected to be high, as the researcher will need to go the institutional websites to gather information. In spite of all the above constraints, the researcher ensured that the data for the study was obtained; also complete the work within the timeline.

1.7. Organization of the Study

This study is organized in five chapters; Chapter one (1) deals with the introduction, which involves the background of the study, statement of the problem, the study's significance and the objectives to the research. Chapter two (2) deals with the relevant literature review related to this study. The Chapter three (3) presents the research methodology, which looks at the research design, the population, and data collection instruments, sampling technique and sources of data. The presentation and analysis of the findings of the study will be discuss in Chapter four (4). The analysis made use of descriptive analysis to evaluate and make meaning out of the data gathered. Finally, chapter five (5) summarized the study by looking at the key findings, conclusions and recommendations.

1.8. Chapter Summary

The entire research is introduced in this chapter. The background of the study, the main objective of the study and the specific objectives, the research questions and research hypotheses were all discussed in this chapter. This chapter also discussed the significance of the study to policy makers, practice, and way forward for future research in this area of study, the limitations of the study and finally ended with the organization of the study.

CHAPTER II

LITERATURE REVIEW

2.1. Introduction

This chapter has seven main sections. The first section explains the concept of innovation and carbon emission in emerging markets. The overview of C02 emission in emerging markets; relationship between innovation and carbon emission; innovation gaps and carbon emission challenges in developing economies; theoretical foundation; and the theory of Environmental Kuznets Curve (EKC).

2.2. Overview of CO2 Emissions in Emerging Markets

The relationship between innovation and CO2 emissions in emerging markets has gained increasing attention in recent years, particularly as these nations face the challenge of achieving economic growth while also ensuring environmental sustainability. Studies suggest that innovation's impact on CO2 emissions can be both positive and negative, depending on various factors such as technological advancements, governance, and local conditions.

In emerging markets, green innovation has proven to be a powerful tool in reducing CO2 emissions. For example, research by Yuan et al. (2022) shows that green innovations have led to significant reductions in CO2 emissions in China, with the quality of institutions further enhancing this effect. On the other hand, some studies highlight the difficulties that developing nations face in implementing green technologies. Dauda et al. (2019) found that innovation, while effective in reducing emissions in developed countries, has had the opposite effect in emerging economies like the BRICS nations, where economic growth often outpaces environmental safeguards.

Udeagha & Ngepah, (2022) focus on South Africa, where technological innovations have helped reduce carbon emissions in both the long run and the short run. However, they note that energy consumption and trade openness can exacerbate emissions if not managed properly. Albitar et al. (2023) further emphasize the importance of governance in this equation, arguing that strong environmental governance frameworks significantly amplify the emissions-reducing potential of innovation. The study by the authors (2021) in European countries also points out that while environmental innovations help lower CO2 emissions in the long run, short run rebound effects can temporarily offset these gains.

These findings underscore the complexity of the relationship between innovation, economic growth, and CO2 emissions in emerging markets. The effectiveness of technological solutions depends heavily on local factors like institutional quality, energy consumption, and governance. Policymakers must consider these dynamics when designing strategies to foster both innovation and environmental protection.

Emerging markets are characterized by rapid industrialization and economic growth, which often result in substantial environmental challenges, particularly in terms of CO2 emissions. In these economies, emissions are largely driven by fossil fuel consumption, deforestation, and industrial activity, often exacerbated by weak regulatory frameworks and the prioritization of economic development over environmental concerns (Pinto-Gutiérrez, 2024). According to the Environmental Kuznets Curve (EKC), emissions initially rise with economic growth but eventually fall as economies adopt cleaner technologies and stricter regulations (Bhat & Ikram, 2024).

Foreign direct investment (FDI) plays a crucial role in shaping environmental outcomes in these regions. In countries with lax environmental regulations, such as China and India, FDI can increase emissions due to the prioritization of economic goals over environmental ones (Bhat & Ikram, 2024). Similarly, financial development (FD) can have dual effects. While it may promote green innovations and energy efficiency, it can also encourage industrial expansion and increased emissions if policies don't emphasize sustainability (Nguyen & Le, 2024). However, renewable energy adoption and technological advancements have shown promise in mitigating emissions. For instance, Vietnam's renewable energy strategies have led to long-term reductions in CO2 emissions, despite short-term industrial pressures (Nguyen & Le, 2024).

Corporate structures in emerging markets also have a significant impact on emissions. In Chile, for example, firms affiliated with business groups have been found to produce higher emissions due to weaker environmental accountability compared to independent firms (Pinto-Gutiérrez, 2024). Despite this, strategies such as green financing, international collaboration, and stricter regulatory frameworks are emerging as effective tools to address CO2 challenges in these regions (Raheem et al., 2020).

Overall, emerging markets face significant hurdles in managing CO2 emissions due to factors like rapid industrialization, increasing energy demand, and reliance on nonrenewable energy sources. The shift to renewable energy and green technologies presents a critical opportunity for reducing emissions in these economies. However, the success of these efforts depends heavily on the economic and regulatory environments in which they are implemented. Studies like those by Hao & Chen, (2023) and Chiu & Zhang, (2023) suggest that renewable energy, coupled with green innovation, can significantly reduce CO2 emissions, but only when accompanied by robust financial systems and effective governance.

Financial development has also been shown to play a key role in mitigating emissions. Gök (2020) conducted a meta-regression analysis showing that financial systems can either exacerbate or mitigate CO2 emissions, depending on how well they align with environmental goals. This highlights the need for policies that channel financial resources into green innovations and sustainable practices, promoting economic development without compromising environmental sustainability.

Finally, emerging markets are at a critical juncture in the global effort to reduce CO2 emissions. While economic growth and industrialization contribute to rising emissions, the adoption of green innovations, renewable energy, and effective governance can provide pathways to reduce emissions. However, these efforts require a delicate balance between economic development and environmental sustainability, with careful policy and institutional support.

2.3. Innovation Gaps and Carbon Emission Challenges in Developing Economies

Innovation has long been recognized as a key factor in driving sustainable development and reducing carbon emissions, especially in developing countries. However, despite the clear potential of technological advancements, these regions face significant challenges when it comes to bridging innovation gaps and effectively addressing carbon emissions. The relationship between innovation and carbon emissions in emerging economies is complex, as many countries struggle to integrate green technologies into their economies due to limitations in finance, infrastructure, and regulation.

The BRICS countries, often considered a representative group of developing economies, are increasingly focused on green innovation as a means to achieve carbon neutrality. Onifade & Alola, (2022) argue that while green technologies have the potential to reduce environmental risks and support economic growth, these nations face significant hurdles when it comes to implementing such technologies on a large scale. These challenges are partly due to disparities in technological development, differences in regulatory frameworks, and varying financial capabilities across the BRICS nations.

Another major issue highlighted in the literature is the difficulty in translating technological advancements from the lab to widespread, real-world application. Yu et al. (2022) point out that while renewable energy innovations have shown promise in reducing carbon emissions, developing economies face substantial barriers in integrating these technologies. These include insufficient infrastructure investment, weak policies to promote the diffusion of innovation, and limited access to international markets for emerging green technologies. Their study on the E7 countries Brazil, China, India, Indonesia, Mexico, Russia, and Turkey emphasizes the importance of policies that not only promote green innovation but also address the systemic challenges these countries face in adopting these innovations.

A key paradox in the innovation debate is the potential for technological progress to unintentionally worsen environmental issues. Narita, (2012) explores how certain energy innovations, particularly in fossil fuel extraction and processing, may increase carbon emissions despite technological advances in other areas. This paradox is especially relevant for developing countries, where innovations aimed at improving fossil fuel industries may offset the benefits of cleaner technologies. Narita stresses that while technological progress is crucial, it must be accompanied by strong policy frameworks to ensure that innovations actually contribute to reducing emissions. This view is supported by (Yu et al., 2022), who note that energy innovations can indeed reduce emissions but only if they are integrated within supportive institutional structures.

Danni Yu et al. (2022)further investigate the threshold effects of innovation in relation to carbon emissions, highlighting that the impact of technological advancements on CO2 emissions depends on the level of economic development and financial capacity. In poorer countries, innovations often exacerbate environmental degradation due to the lack of adequate infrastructure, regulatory oversight, and financial resources for large-scale implementation. The threshold effect suggests that countries need to reach a certain level of economic maturity and financial strength before innovations can lead to meaningful emissions reductions. This finding echoes Narita's, (2012) concerns that without appropriate governance, technological innovation can sometimes create more harm than good, particularly in sectors like energy where market failures are common.

The need for a balanced approach that combines both innovation and policy is evident in Onifade & Alola (2022) call for creating enabling environments in developing countries. These environments should focus on improving access to clean energy technologies, promoting entrepreneurship in the green technology sector, and fostering regional cooperation to share knowledge and reduce the costs of innovation. The authors argue that innovation policies should be designed with a long-term vision, ensuring that economic growth does not come at the expense of environmental sustainability.

Moreover, despite having access to renewable energy technologies, developing economies often face a mismatch between technological potential and actual implementation. This gap is due to factors such as inadequate training, the absence of strong innovation ecosystems, and insufficient financial incentives. Narita (2012) supports this view by emphasizing the critical role of policy decisions in determining whether developing nations can leapfrog to sustainable development or fall into a pattern of rising emissions due to inadequate governance.

Innovation in renewable energy is also seen as crucial for addressing carbon emissions. Studies show that while renewable energy technologies have the potential to reduce emissions, the speed of their adoption varies significantly across developing countries. A key obstacle is the lack of investment capacity. Onifade & Alola, (2022) highlight that many developing nations struggle with financing green innovations, limiting their ability to deploy these technologies at scale. This financial barrier is compounded by the lack of regulatory frameworks that can support and incentivize green investments. Governments in these countries need to establish strong frameworks that encourage both public and private sector investments in green technologies, ensuring that innovations are not only financially supported but also environmentally sustainable.

In conclusion, while green innovations offer a promising solution for reducing carbon emissions, developing countries face multiple barriers that prevent them from fully realizing the potential of these technologies. These barriers include gaps in infrastructure, financing, policy frameworks, and technological capabilities. Overcoming these challenges will require a coordinated effort from governments, international organizations, and the private sector to create policies that not only encourage the adoption of new technologies but also integrate them into broader environmental and economic development strategies.

2.4. Relationship Between Innovation and CO2 Emissions

The relationship between innovation and CO_2 emissions is multifaceted, with technological and green innovations emerging as key players in reducing environmental impact. Various studies have explored how different forms of innovation ranging from technological advancements to financial mechanisms and green energy adoption contribute to curbing emissions. For instance, Liu et al. (2022) highlight how technological innovations in Chinese provinces lead to more efficient carbon reduction practices, suggesting that areas with greater technological progress tend to be more effective in managing emissions. Similarly, Hao & Chen (2023) show that in the E7 countries, the integration of green innovations, particularly in renewable energy, significantly helps reduce emissions. Their findings are echoed by Zhang et al. (2021), who point out that financial development plays a very important role in improving the effectiveness of renewable energy technologies by moderating the relationship between energy consumption and CO_2 emissions.

Yu et al. (2022) explore a slightly different angle, examining how economic complexity alongside technological innovation influences CO_2 emissions in N-11 countries. They found that increased complexity within an economy, coupled with technological advancements, leads to improved industrial practices that help reduce emissions. Gök (2020) offers a broader view in his meta-analysis, showing that while financial development can sometimes lead to higher emissions due to increased industrial activity, it also fosters innovations that mitigate the effects of these emissions. His findings suggest that innovation's role in emissions management is complex and depends on how well financial systems integrate with technological advancements. These studies demonstrate that innovation whether it’s technological, green, or economic is crucial for reducing CO_2 emissions, though the specific outcomes depend heavily on regional contexts, economic structures, and policy environments.

In examining the broader trend, researchers emphasize the role of innovation in achieving sustainability. (Tekin Turhan et al., 2023) stress that financial sector development and innovation in emerging economies can foster cleaner technologies and renewable energy adoption, contributing to emissions reductions. Likewise, Yu et al. (2022) find that while innovations may initially increase emissions by boosting industrial output, over time, they drive down emissions by facilitating the transition to energy-efficient, low-carbon technologies. Technological advancements in renewable energy, particularly in monitoring systems, also improve the efficiency of carbon emission reductions, as highlighted by (Xu, 2023).

At the same time, the relationship between innovation and emissions is not straightforward. Raheem et al. (2020) examine the impact of information and communication technology (ICT) and financial development in G7 countries. While ICT has long-term growth benefits, it can also increase emissions, showing the delicate balance needed between technological growth and environmental goals. Pinto-Gutiérrez (2024) explores how business group structures in Chile influence emissions, noting that the type of innovation adopted by industries plays a significant role in determining whether the environmental outcome is positive or negative. The research by Bhat & Ikram (2024) in the Asia-Pacific and Oceanian regions also suggests a nuanced relationship, where foreign investment and financial development moderate emissions, with the effect depending on the region's innovation strategy.

In emerging economies like Vietnam, Nguyen & Le (2024) found that while ICT infrastructure and renewable energy play important roles in reducing emissions, it is technological innovation that stands out as the long-term driver for sustainability. Their research underscores that when supported by the right policies and financial investment, innovations in energy sectors and green technologies can significantly reduce CO_2 emissions, making it clear that the path to sustainability involves a mix of innovative efforts across various sectors.

2.5. Theoretical Foundation

2.5.1. Innovation's Role in Environmental Sustainability

Innovation has a significant role in advancing environmental sustainability, primarily by improving resource efficiency and facilitating the shift to low-carbon technologies. A number of studies underline how technological innovations, particularly in information and communication technology (ICT), as well as financial development, contribute to reducing CO_2 emissions and promoting sustainable economic growth. Raheem et al. (2020) explore the effects of ICT and financial development across G7 nations, showing that while ICT positively influences economic growth over the long term, it also helps reduce emissions by fostering more efficient, sustainable industrial practices. Similarly, Pinto-Gutiérrez (2024) looks into the impact of business group affiliations on CO_2 emissions in Chile, revealing that business innovations, particularly those focused on sustainability, can reduce industrial pollution.

Nguyen & Le, (2024) delve into the role of technological innovation, renewable energy consumption, and ICT infrastructure in emerging economies, with a particular focus on Vietnam. Their study shows that combining these elements can lower CO_2 emissions, especially in industries that have traditionally relied on fossil fuels. In addition, Bhat & Ikram (2024) explore how financial development and foreign direct investment (FDI) in the Asia-Pacific region interact with CO_2 emissions. They find that FDI brings in green technologies that help reduce emissions, particularly when supported by solid financial infrastructure.

The importance of technological and financial innovations is even more evident in the context of emerging economies, where Liu et al., (2022) demonstrate how technological advancements significantly reduce emissions by boosting energy efficiency and promoting the use of cleaner energy sources in China. This is reinforced by Yu et al., (2022), who argue that innovations in energy technology and economic complexity can lead to reductions in CO_2 emissions in the N-11 countries.

Hao & Chen (2023) further elaborate on this by discussing how green innovations, especially in renewable energy, can significantly curb emissions in the E7 countries. They, along with Chiu & Zhang (2023), emphasize the role of financial development in facilitating the transition to renewable energy by supporting technological advancements in the energy sector. Gök (2020), in a meta-regression analysis, similarly asserts that financial development can drive economic growth, but its contribution to emissions reduction is contingent upon fostering green technologies.

Altogether, these studies highlight how innovation, especially in the areas of technology and finance, is essential for reducing CO_2 emissions. Technological advancements, particularly those aimed at improving energy efficiency and promoting renewable energy, are critical drivers in this process. However, the effectiveness of these innovations is often amplified by strong financial and policy mechanisms that support their integration into national systems, ultimately contributing to long-term environmental sustainability goals.

2.5.2. Technological Progress and CO2 Emissions

Technological progress is increasingly recognized as a pivotal factor in reducing CO_2 emissions and steering the global economy towards sustainability. While it's true that technological advancements can initially lead to a spike in emissions—due to expanded industrial activities—the long-term benefits are substantial, offering new and innovative ways to curb climate change. Over the last few decades, technological developments, especially in energy systems and cleaner production methods, have opened doors to more energy-efficient solutions that help reduce emissions over time.

For instance, according to Raheem et al. (2020) ICT plays a vital role in boosting long-term economic growth, while also facilitating cleaner industrial practices that ultimately help reduce CO_2 emissions. This is particularly important because, when paired with strong financial development, these technologies improve energy efficiency and promote the wider adoption of renewable energy, aligning with broader carbon reduction strategies. Similarly, Yu et al., (2022) explore the intersection of economic complexity, technological innovation, and CO_2 emissions in the N-11 countries, emphasizing that innovations in technology are not just about improving industrial efficiency but are also key to transitioning to renewable energy sources. These shifts are critical to supporting sustainable growth, as they help reduce emissions while simultaneously boosting economic resilience.

Chiu & Zhang (2023) delve into the moderating role of financial development in the relationship between renewable energy consumption and CO_2 emissions. They reveal that financial development accelerates the adoption of green technologies, playing a central role in reducing carbon emissions. For example, innovations in energy technologies, particularly in solar and wind systems, have made great strides in reducing emissions. In this regard, Hao & Chen (2023) affirm that green innovation especially in renewable energy sectors is essential for curbing emissions, particularly in nations that rely heavily on energy consumption.

Adding to this, Gök (2020) provides a meta-analysis on the impact of financial development on CO_2 emissions, acknowledging the difficulty of quantifying its effects due to varying technological advancements across regions. However, Gök emphasizes that financial development can be a major driver of innovation in the energy sector, ultimately reducing emissions when coupled with the right policies and investment strategies. This highlights the importance of creating conducive financial environments that foster technological innovation, thus facilitating emission reductions.

Ultimately, the body of literature suggests that technological advancements in energy efficiency, renewable energy technologies, and ICT play a critical role in reducing CO_2 emissions. However, the overall success of these innovations is intricately linked to the financial, policy, and economic environments in which they are deployed. Countries that embrace technological progress, particularly in their energy systems, are not only positioned to lower their carbon footprints but can also facilitate a transition to a low-carbon economy, driving sustainable economic growth in the process.

2.5.3. Innovation – Environment Nexus

The intersection of innovation and environmental sustainability has become a key focus of research, as technological and organizational innovations offer essential solutions to address climate change and environmental degradation. The relationship between innovation and environmental outcomes is intricate, involving the dynamic interaction between green technologies, financial systems, institutional policies, and regulatory frameworks. A growing body of literature highlights how innovation can not only reduce CO_2 emissions but also promote sustainable economic growth.

For example, Huan & Qamruzzaman (2022) explore the interaction between financial innovation, technological and environmental innovation, and foreign direct investment (FDI) in the BRIC countries. Their study shows that financial innovation plays a pivotal role in supporting technological and environmental innovations, which, in turn, drive sustainable development. By facilitating the flow of resources into green technologies and sustainability projects, financial innovations help tackle environmental challenges. This research emphasizes the importance of fostering an innovation ecosystem that integrates financial, technological, and environmental objectives to enhance sustainability.

Li et al. (2022) take a closer look at how innovation can mitigate climate change, specifically within the energy-environment-growth nexus. They argue that innovation in energy technologies is essential for balancing economic growth with environmental sustainability. Their research, which spans both OECD and non-OECD nations, underscores that investments in clean energy technologies are crucial for reducing CO_2 emissions while maintaining economic performance. The study suggests that technological innovations in energy systems are central to achieving sustainable growth by decreasing dependence on non-renewable energy and promoting the widespread use of sustainable power alternatives.

Ma et al. (2023) expand on this by examining the role of digital transformation in driving corporate environmental green innovation. They find that digital technologies not only improve operational efficiency but also enhance companies' ability to innovate in environmentally sustainable ways. Through digital tools, companies can optimize energy use, manage resources more efficiently, and reduce emissions, thereby accelerating green innovation. Their study highlights the role of digital transformation as a catalyst for sustainable business practices.

Mady et al. (2024) focus on how regulatory pressures and demand for eco-friendly products drive innovation in small and medium-sized enterprises (SMEs). Their research illustrates how eco-innovation serves as a mediator between regulatory requirements and consumer demand for sustainable products. By innovating to meet these pressures, SMEs not only reduce their environmental footprint but also strengthen their market position. This study emphasizes the importance of aligning regulatory frameworks with consumer demand to foster innovation and promote sustainability.

Peng & Jia (2023)explore the organizational factors that drive environmental innovation. Their research shows that organizational climates that prioritize sustainability and foster a culture of innovation are more likely to produce solutions that contribute to environmental sustainability. The physical environment within organizations can influence innovation levels, particularly in green technologies, by encouraging sustainability-driven practices and a forward-thinking approach.

The relationship between innovation and environmental sustainability is increasingly recognized as crucial for addressing global environmental challenges, particularly in terms of reducing CO_2 emissions. Technological innovation, especially in energy systems, is key to transforming sustainability efforts by introducing more energy-efficient methods, promoting cleaner production processes, and advancing green practices across industries. Both academic and policy research has intensified in recent years, with several studies highlighting the importance of green innovation, financial development, and institutional frameworks in improving environmental outcomes.

Johl & Toha (2021) investigate the connection between proactive eco-innovation and firm financial performance in the context of a circular economy. They find that proactive eco-innovation not only leads to environmental benefits, such as reduced emissions and resource efficiency, but also boosts financial performance by enhancing competitiveness and resource management. This dual benefit of eco-innovation highlights its significance in promoting both sustainability and economic growth.

Nan et al. (2022) study the role of green innovation in China's economic growth and CO_2 emissions, using the PSTR model. Their findings underscore that green innovation is central to reducing CO_2 emissions while fostering economic growth. Their study emphasizes that advancements in energy efficiency and renewable energy are crucial for China's long-term sustainable development strategy.

Du et al. (2022) examine the interplay between financial development, technological innovation, and environmental quality within OECD countries. Their research shows that financial development, combined with strong institutional quality, plays a crucial role in facilitating technological innovations that enhance environmental outcomes. By creating a conducive environment for innovation and providing access to capital for green technologies, financial development is key to improving environmental quality across developed economies.

Balsa-Barreiro et al. (2023) explore the broader relationship between innovation and environmental sustainability, emphasizing that innovation—particularly in green technologies—is vital for achieving long-term environmental goals. They suggest that the integration of innovation and environmental policies can create synergies, leading to improved sustainability outcomes.

Li et al. (2023) provide a unique perspective by analyzing how environmental corporate social responsibility (CSR), green intellectual capital, and green innovation interact in Chinese automobile manufacturing firms. Their study finds that a firm's commitment to environmental CSR, when coupled with green innovation and intellectual capital, can lead to better sustainability outcomes. This suggests that environmental responsibility in corporate strategies can stimulate innovation, which then drives further environmental benefits, creating a cycle of innovation and sustainability.

In conclusion, these studies highlight the complex relationship between innovation and environmental sustainability. Technological innovations, particularly those aimed at enhancing energy efficiency and promoting renewable energy, are crucial for reducing CO_2 emissions and achieving sustainable growth. Financial development, institutional quality, and corporate strategies that incorporate environmental goals also play vital roles in facilitating the transition to a greener economy. Together, these studies underscore the importance of integrating technological, financial, regulatory, and organizational innovations to meet the environmental challenges of our time. The innovation-environment nexus is not only about creating new technologies but also about building an ecosystem that supports sustainable business practices, regulatory compliance, and the adoption of green technologies.

2.6. Theory of Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve (EKC) theory proposes that economic growth and environmental deterioration have an inverse U-shaped relationship (Grossman & Krueger, 1995). The Environmental Kuznets Curve (EKC) came to prominence as far back 1990s after the early studies by Kuznets (1955). Kuznets (1955) proposed that during economic growth, income disparity initially increases to a peak before starting to decrease as per capita income rises. The concept of the Environmental Kuznets Curve (EKC) has become a topic of considerable discussion among scholars studying environmental issues and economic development. The Environmental Kuznets Curve (EKC) was derived when Grossman and Krueger (1995) did a study to investigate the impact of economic development on environmental quality.

The Environmental Kuznets Curve (EKC) theory suggests that as a nation's economy grows, its environmental impact initially worsens. However, once the country reaches a certain level of economic development, environmental conditions start to improve. This hypothesis outlines three (3) distinct phases: the pre-industrial stage, the industrial stage, and the post-industrial stage. According to this model, environmental degradation increases during the early stages of economic growth, but after reaching a turning point, further economic progress leads to environmental enhancement. At the pre-industrial stage, environmental degradation worsens. This is because at the pre-industrial stage, there is rapid industrialization, increasing emissions from urbanization, weak environmental laws and pollution regulations, limited technology and heavy reliance on dirty fuel such as coal. These emissions also stem from manufacturing of cement and fossil fuels, which produces carbon dioxide emissions.

At the industrial stage, the economy reaches a pivotal moment known as the 'income turning point,' which extends into the post-industrial phase. During this latter stage, various factors contribute to a reduction in environmental degradation, including high innovation rates, strict environmental regulations, government policy interventions, shifts in GDP structure, and the implementation of smart urbanization policies. Numerous studies have been conducted on this topic, with some findings supporting this hypothesis and others yielding conflicting results.

Research by Shahbaz and Leitao (2015) identified a direct connection between economic growth and carbon dioxide emissions in Portugal, confirming the existence of the Environmental Kuznets Curve (EKC). Similarly, Apergies and Ozturk (2015) found evidence supporting the EKC in Asian countries. Ntow-Gyamfi et al. (2020) examined the EKC and discovered a positive relationship between carbon dioxide emissions and economic growth, also testing for the presence of EKC. Using annual data from 1974-2016, Shahbaz et al. (2019) demonstrated that the EKC exists only in the long-term in Vietnam, not in the short-term. They suggested that an N-shape better explains the long-term relationship between income and pollution.

In contrast, Burnett et al. (2013) identified a long-term relationship between carbon dioxide emissions and personal income, but their results did not support the presence of

EKC. This study concluded that economic growth influences emission intensities rather than absolute emissions. Twerefou et al. (2016) presented contradictory findings, revealing a U-shaped relationship between economic growth and carbon dioxide emissions when using per capita GDP as a measure for both variables. Their research, based on annual data from 1970-2010, indicated that trade openness and energy consumption are positive long-term drivers of carbon dioxide emissions. Sarkodie and Strezov (2018) conducted a review of EKC studies using bibliometric and meta-analysis techniques. Their research identified China as the most frequently mentioned term, and the meta-analysis revealed a turning point at an annual income of US$8,910. They postulated that most studies on Environmental Kuznets Curve (EKC) are based atmospheric indicators such as carbon dioxide emissions and temperature change anomalies, while studies on Environmental Kuznets Curve (EKC) that have employed land, freshwater and biodiversity indicators are limited. Webber and Allen (2010) argue that nations should prioritize economic growth over implementing environmental policies prematurely.

The evidence supporting the Environmental Kuznets Curve (EKC) hypothesis, particularly in relation to CO2 emissions, remains mixed. Initially, studies suggested that as economies industrialize, they tend to increase their reliance on fossil fuels, which inevitably leads to higher pollution levels. However, as these economies mature and adopt more advanced technologies, energy efficiency improves, and cleaner production processes are implemented, causing emissions to eventually decline (Grossman & Krueger, 1991). This shift toward cleaner industries is often facilitated by technological innovation, especially in sectors like energy and manufacturing, which can help mitigate the environmental costs of industrial growth.

Technological innovation plays a key role in these improvements. As economies become wealthier, they are more inclined to invest in green technologies and cleaner industries, which are generally less carbon-intensive Xiaoyang et al. (2022). Innovations in renewable energy, waste management, and energy efficiency are especially crucial in reducing emissions in developed countries. However, in low-income nations, where industrialization is still largely driven by cheap, polluting technologies, such innovations remain out of reach.

The situation in emerging markets is more complicated. While technological innovations have the potential to reduce CO2 emissions, economic growth in these markets is often still tied to energy-intensive industries. This makes the EKC hypothesis less applicable in these contexts, as many emerging economies may never reach the “turning point” where environmental quality improves on its own, unless substantial external interventions or innovations occur Afrifa et al. (2020); Huang et al. (2022).

Despite its popularity, the EKC hypothesis has faced considerable criticism for oversimplifying the relationship between the growth of economies and environmental degradation. Critics argue that the model fails to account for the relocation of polluting industries to countries with weaker environmental regulations or the influence of global environmental policies. Additionally, assuming that all countries follow the same emissions trajectory is problematic, particularly in developing nations where the use of coal and other polluting energy sources often leads to rising emissions Zhang et al. (2021). Furthermore, the EKC overlooks the uneven distribution of environmental benefits and burdens across different regions within a country.

For emerging markets, reaching the "turning point" as suggested by the EKC is a daunting challenge. These economies are more vulnerable to the negative effects of pollution and climate change. To overcome this, effective policy interventions such as carbon taxes, emission trading systems, and subsidies for green innovation are essential to accelerate the shift toward sustainable development. By combining innovation in green technologies with supportive policies, these economies can bypass the most polluting stages of development and leap directly to cleaner, more efficient production methods (Huang et al. (2022); Xiaoyang et al. (2022).

CHAPTER III

RESEARCH METHODOLOGY

3.1. Introduction

An empirical literature review reveals different estimation methods employed in analyses in some studies conducted on innovation and carbon emission. Some researchers analyzed reports and surveys by international financial institutions (Więckowska, 2013), Bloomberg identifications (Baker, M., Bergstresser, D., Serafeim, G., & Wurgler, J. 2018), untapped potentials of Indians' institutional investors (Guha, 2019), comparative analysis (Moid, 2017), two-stage Nash equilibrium (Tsiropoulos, 2019), interviews by engaging investors and issuers (Wood & Grace, 2011), design features of Eurobonds (Waibel, 2016), panel error-correction model (Senga, C., Cassimon, D., & Essers, D. (2018), system generalized method of moments (GMM) (Boachie-Yoadom & Mensah, 2021) and quantitative analysis (Tsiropoulos, 2016). However, the choice of econometric technique employed in a study is solely dependent on the objectives and the variables used for the study. Most studies related to this area of study did not collect data and analyze data using an empirical model to get their findings. The study collects a secondary data and employ a panel estimation model to analyze the data for findings.

The chapter describes the econometric technique used in determining the relationship between innovation and CO2 emission in emerging markets. This chapter discusses the dataset used in assessing the relationship between these variables, the estimation method and the statistical programmed. First, the study looks at the theoretical foundations of the empirical model employ for analyzing the dataset. The justification ensures that the right methodology about the appropriate econometric techniques for the analysis is employ for the study. The next section of this chapter discusses the how the econometric technique used for the study is applied in some empirical studies related to this topic of study. The estimation techniques (both pre-estimation and post-estimation) as well as some diagnostic tests on the model are presented in the next section. Finally, the chapter discusses the justification of the variables and their sources in which they were collected used for the study.

3.2. Research Design

This research is explanatory and quantitative in nature. In quantitative research, hypotheses must be formulated and observable and measurable data must be gathered (Salkind, 2010). In carrying out quantitative research, the researcher to go through rigorous processes in order to answer the research questions and to arrive at generalized and objective findings (Yauch and Stendel, 2003). Explanatory research is quantitative in nature, which allows hypotheses to be tested by measuring relationships between variables; the data are analyzed using statistical techniques or software (Given, 2008). This study establishes the relationship between the two main variables, that is, innovation and carbon emission. The fundamental philosophy underlying quantitative research is positivism, which is based on the scientific method of research (Salkind, 2010). The fundamental philosophy underlying this study will be positivism by undergoing the scientific process of carrying out quantitative research. The scientific method in research involves an empirical or theoretical basis for the investigation of population and samples (Salkind, 2010). The objective of the study is to assist insights about the role of innovation in carbon emission and mitigation efforts, and to help advocate a course of action. This study employed STATA 17.0 software as an analysis technique to analyze the data.

3.3. Data, Sources, and Sample Size

This research mainly used secondary data from World Development Indicators (WDI) database respectively. The study used panel data, which comprises of time series and cross-sectional data to deal with variations across countries and over time. The empirical analysis looked at the potential impact of innovation on carbon emission in emerging markets. The population of this study constitutes 23 emerging markets according to the MSCI Emerging Markets Index. The study uses a sample 22 emerging markets. Of the 23 emerging markets, 22 were used for the analysis, thus, excluding Taiwan because it is not classified as an independent country as per the world development indicators database, therefore the research will consider all emerging markets excluding Taiwan due to data unavailability. The study data is restricted to the period 2000 to 2020.

The variable carbon dioxide emissions is measured in percentage (%) GDP. Research and development expenditure is measured as (%) of GDP. Domestic credit to private sector is measured as a (%) of GDP. Urbanization is measured in percentage (%) of GDP. Trade openness is measured as the sum of imports and exports expressed as a percentage of GDP. Economic growth is measured in percentage (%) annual GDP; Financial development is measures by Bank Z-score, Industrialization is measured as industry value added (%) of GDP and Mobile cellular subscriptions.

3.4. Data Description

The dependent variable for this study is climate change, whilst the explanatory variable is Eurobonds. Carbon dioxide emissions will be use as a proxy for the dependent variable that is climate change. The main explanatory variable is Eurobonds.

LNCO2 - Logarithm of Carbon Emission

GDP – Economic Growth

LNINDS – Logarithm of Industrialization

LNTRADE – Logarithm of Trade Openness

LNMCS- Logarithm of Mobile cellular subscriptions

LNFD- Logarithm of Financial Development

LNURB - Logarithm of Urbanization

LNRnD - Logarithm of research and development

LNDCR - Logarithm Domestic credit to private sector

- *Estimation Technique*

The study employed the panel estimation methods, that is, random effects and fixed effects models to estimate the first and second objectives that is to assess the relationship between innovation and CO2 emission. The second objective will assess whether innovation reduces or worsens CO2 emission.

- *Model Specification*

Following a panel data for the empirical analysis, the study follow literature by adopting panel data models for analysis approach to panel data estimation in assessing the relationship between innovation and C02 emission. Ideally, panel data models are applied when a dataset is a combination of cross-section and time series (Wooldridge, 2013). The general panel model is specified below. In specifying the model, the dependent variable (C02 emission) will be a function of the explanatory variable (Innovation).

CO2 Emission = f (Innovation, CONTROLS)

Consequently, the equations will be specify as:

The general panel regression estimator is specified as:

$$Y_{\mathrm{it}} = \beta_0 + \beta_1 \mathrm{X}_{\mathrm{it}} + \ldots\ldots\ldots\ldots + \beta_{\mathrm{n}} \mathrm{X}_{\mathrm{it}} + \varepsilon_{\mathrm{it}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$i = 1, \ldots, N \quad t = 1, \ldots\ldots, T$$

From the equation 1 above, i indexes all the 17 emerging markets understudy, t represents the time effect specified, $\varepsilon_{\mathrm{it}}$ represents idiosyncratic error term in the model, Y_{it} represents the dependent variable (CO2 emission), β_0 denotes the constant term for all periods, β_1 represents the coefficient of the independent variable (Innovation), β_{n} represents vector of coefficient of control variables to be estimated and X_{it} denotes vector of observations on the explanatory variables and control variables included in the model.

The multiple linear panel model specification

$LNCO2_{it} = \delta_o + \delta_1 LNRnD_{it} + \delta_2 LNFD_{it} + \delta_3 LNMOCS_{it} + \delta_4 LNURB_{it} + \delta_5 GDP_{it} + \delta_6 LNINDS_{it} + \delta_7 LNTRADE_{it} + \delta_8 LNDCR_{it} + \epsilon_{it}$ .... (2)

In this context, CO2 emissions, industrialization, mobile cellular subscriptions, financial development, urbanization, economic growth, research and development, trade openness, and domestic credit to the private sector are all represented by logarithmic values. The coefficients of the explanatory variables are denoted by β, while ε represents the error term.

The Environmental Kuznets Curve (EKC) suggests that economies reach a pivotal point, known as the "industrial stage," after which they transition into a post-industrial phase. This transition necessitates the inclusion of a squared term for the explanatory variable (RnD) to accurately represent this turning point. Consequently, a squared term is incorporated into equation 2, resulting in:

$LNCO2gdp_{it} = \delta_0 + \delta_1 LNRnD_{it}^2 + \omega' X_{it} + \varepsilon_{it}$ ……………………………… (3)

From equation 3, $LNCO2gdp_{it}$ is the carbon dioxide emissions, δ_0 denotes the constant term, δ_1 indicates the coefficient of the squared value of Innovation ($LNRnD_{it}^2$), ω' represents the coefficients of control variables and X_{it} indicates all the control variables.

$LNCO2_{it} = \delta_o + \delta_1 LNRnD_{it} + LNRnD_{it}^2 + \delta_2 LNFD_{it} + \delta_3 LNMOCS_{it} + \delta_4 LNURB_{it} + \delta_5 GDP_{it} + \delta_6 LNINDS_{it} + \delta_7 LNTRADE_{it} + \delta_8 LNDCR_{it} + \epsilon_{it}$ .... (4)

- *Definition of Variables*

- **Overview of Explanatory Variables, Their Anticipated Effects, and Data Origins**

Table 3.1. Summary of Explanatory Variables, Their Expected Signs, and Sources of Data

Variable	Expected sign	Data source
Financial Development	Positive	World Development Indicators
Trade Openness	Positive	World Development Indicators
Research & Development	Positive	World Development Indicators
Industrialization	Positive	World Development Indicators
Urbanization	Positive	World Development Indicators
Economic growth	Positive	World Development Indicators
Domestic Credit	Positive	World Development Indicators
Mobile Cellular Subscription	Positive	World Development Indicators

Sources: Author's own construction (2024)

3.5. Data Analysis

Data was analyzed using a quantitative methodology. The quantitative data was analyzed using the Stata 17.0 software. Carbon dioxide (CO2gdp) is the dependent variable is used as a proxy to measure carbon emission. The main independent variable is innovation which was measured as research and development. The control variables included financial development, economic growth, urbanization, domestic credit, mobile subscription, industrialization and trade openness. All the variables were log transformed with the exception of economic growth. This is because; negative values cannot be log transformed. Again, log-transforming variables according to literature is for scaling purpose and for easy interpretation. The pooled, fixed and random effect model were estimated using Stata 17.0. To know the appropriate model for the study, a Hausman test was conducted to decide on the best model to use for the study.

CHAPTER IV

ANALYSIS RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents an analysis of key study findings, commencing with descriptive statistics and the correlation matrix. The panel dataset is evaluated using the OLS panel approach to investigate the relationship between innovation and CO_2 emissions in emerging markets. Furthermore, the chapter examines the Environmental Kuznets Curve (EKC) and assesses the influence of financial development, investments, urbanization, and economic growth on CO_2 emissions. The estimation methodology is delineated, elucidating how the analysis fulfilled the study's objectives. Subsequently, results are presented and interpreted, providing a summary of statistics for both dependent and explanatory variables. The findings are then compared with extant literature to contextualize the results and draw conclusions.

4.2. Descriptive and Correlation Analysis

4.2.1. Descriptive Statistics

The descriptive summary statistics presented in Table 4.1 are for 17 developing countries for the period 2000-2020. The table reported statistics of interest to this study and they are the observations, the average (mean), standard deviation, minimum values and maximum values of the variables. Descriptive statistics helps to present the data in a meaningful way, which allows simple interpretation of the data. More so, it helps to explain the basic features of the data in a study. Data is summarized through the given observations in the descriptive statistics and it communicates information about the data set.

Table 4.1. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnco2	357	1.405	.704	-.124	2.503
lnfd	334	2.438	.497	-.138	3.265
lnrnd	328	-.35	.818	-2.895	1.568
lndcr	340	4.073	.64	2.505	5.209
lninds	357	3.399	.245	2.592	3.882
lnmocs	357	4.22	.908	-1.086	5.203
lntrade	357	4.168	.529	3.096	5.395
lnurb	357	4.162	.289	3.32	4.474
gdp	357	3.55	3.642	-10.87	14.231

Source: Field Data, 2024

4.2.2. Correlation Matrix Analysis

Correlation analysis examines the linear relationship, not causality, between dependent and independent variables. It quantifies the strength of their association (Wooldridge, 2013) and addresses multicollinearity issues. Correlation coefficients range from -1 to +1. The correlation matrix, generated by STATA, reports these coefficients, indicating the direction of the linear relationship. A coefficient of +1 denotes a perfect positive linear relationship, -1 indicates a perfect negative linear relationship, and 0 signifies no linear relationship. Positive correlations indicate variables moving in the same direction, while negative correlations indicate movement in opposite directions (Brooks, 2008). The correlation matrix also reports the statistical significance of these relationships. Statistically significant coefficients indicate significant linear relationships at a given significance level. A pairwise correlation test was employed to identify multicollinearity issues, as presented in Table 4.2, which reports the pairwise correlation matrix for variables in the carbon dioxide emissions model.

Table 4.2. Pairwise Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) lnco2	1.000								
(2) lnbzs	-0.124	1.000							
	(0.023)								
(3) lnrnd	0.603	0.149	1.000						
	(0.000)	(0.009)							
(4) lndcr	0.473	-0.032	0.449	1.000					
	(0.000)	(0.570)	(0.000)						
(5) lninds	0.019	0.302	-0.005	0.084	1.000				
	(0.727)	(0.000)	(0.923)	(0.124)					
(6) lnmocs	0.477	0.003	0.264	0.339	-0.103	1.000			
	(0.000)	(0.963)	(0.000)	(0.000)	(0.052)				
(7) lntrade	0.564	-0.242	0.245	0.262	0.312	0.321	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
(8) lnurb	0.316	-0.080	0.057	-0.006	-0.292	0.428	0.033	1.000	
	(0.000)	(0.147)	(0.306)	(0.918)	(0.000)	(0.000)	(0.533)		
(9) gdp	-0.102	0.205	0.037	0.003	0.454	-0.239	-0.034	-0.319	1.000
	(0.055)	(0.000)	(0.501)	(0.955)	(0.000)	(0.000)	(0.526)	(0.000)	

Source: Field Data, 2024

The correlation matrix reveals several key relationships between the variables. CO2 emissions are positively correlated with trade openness, mobile cellular subscription, R&D expenditures, and domestic credit, indicating that the increase in these economic activities results in an increase in CO2 emissions. The results also show a weak negative correlation between CO2 emissions and financial development.

Trade openness and mobile cellular subscription have a strong relationship with CO2 emissions and with each other, while GDP shows a positive correlation with industrialization however a negative relationship with mobile subscription. Urbanization correlates positively with mobile subscription and CO2 emissions but negatively with industrial activity.

Overall, the matrix suggests that economic growth and environmental factors like CO2 emissions are interconnected, with trade openness and mobile cellular subscription playing significant roles in this dynamic. Negative correlations with GDP and certain sectors warrant further investigation.

4.3. Model One

4.3.1. Empirical Estimation

The empirical results focus on examining the relationship between innovation and CO_2 emissions. The first model serves as the base model, analyzing the direct link between innovation and carbon emissions. To test for the presence of the Environmental Kuznets Curve (EKC), the square term of innovation was added to the model. This inclusion helps determine whether there is a quadratic, inverted "U"-shaped relationship between innovation and CO_2 emissions, indicating the turning point at which economic growth shifts toward reducing emissions. Additionally, Panel Corrected Standard Errors (PCSEs), pooled OLS, and fixed-effects model results were used for both objectives one and two, serving as benchmarks and enabling a comparative analysis of the findings.

4.3.2. Test for Time Effect

The pooled OLS model assumes that there are no differences between the countries being studied or across time. In contrast, both the fixed effects (FE) and random effects (RE) models account for differences between countries and over time. To determine if such differences exist, a Breusch-Pagan Lagrange Multiplier (LM) test was performed. The null hypothesis of this test suggests that there are no differences over time in the pooled OLS model, while the alternative hypothesis proposes that time differences do exist. The table below presents the results from the Breusch-Pagan Lagrange Multiplier test for random effects.

Table 4.3. Test for a Panel Effect

Breusch and Pagan Langrangian multiplier test for random effects	
Chi-square value	1519.60
P-value and Prob>chi2	0.0000

Source: Field Data, 2024

From the table above, the LM test shows a p-value of 0.0000, which is less than 0.05, this indicates that we reject the null hypothesis and accept the alternative, which says there are differences in time in the pooled OLS model. This means there are random effects among the countries.

4.3.3. The Hausman Test

The Hausman test is conducted to determine whether random effects or fixed effects model is the most appropriate model for the estimation. The null hypothesis states that the random effect is the appropriate model or the individual effect does not correlate with the explanatory variable. The alternative states that the fixed effect is the appropriate model or the individual country effect correlate with the explanatory variables.

Table 4.4. Hausman Test for Fixed Effects and Random Effect

Hausman (1978) specification test	Coef.
Chi-square test value	-295.11
P-value	1

Source: Field Data, 2024

From the output generated in Table 4.4, the results show a significant value higher than the 5% level of significance thus a p-value of 1 and a chi-square test value of -295.11 and. The p-value of 1 means that the test did not reject the null hypothesis and, therefore, supports the preference of the random effects model over the fixed effects model. However, the negative chi-square value indicates an unreliable result due to some negative variance estimates or other numerical issues common for a standard form of the Hausman test in cases when its assumption of positive definiteness is violated. Therefore we proceed to run the Hausman Sigmamore test.

Table 4.5. Hausman Test for Fixed Effects and Random Effect, Sigmamore

Hausman (1978) specification test	Coef.
Chi-square test value	39.605
P-value	0

Source: Field Data, 2024

The Hausman Sigmamore test is a robust version of the Hausman test. From table 4.5, $\chi 2$ at 39.605 and the p-value at 0 leads to the rejection of the no effect. Thus, the fixed effects model is an improvement over the random effects model. A zero p-value indicates very strong evidence that the fixed effects model fits the data better.

4.3.4. Results of the Panel Regression for Objective One

Using a fixed effects panel regression model, the results of the model are reported in table above.

Table 4.6. Regression Results of the Impact of Innovation on $C0^2$ Emission

lnco2	Coef.	St.Err.	p-value	Sig
lnbzs	-.104	.032	.001	***
lnrnd	-.101	.024	0	***
lndcr	.056	.027	.037	**
lninds	.529	.099	0	***
lnmocs	.099	.01	0	***
lntrade	-.286	.041	0	***
lnurb	1.668	.14	0	***
gdp	.008	.002	0	***
Constant	-6.576	.764	0	***
Mean dependent var	1.417	SD dependent var	0.710	
R-squared	0.688	Number of obs	294	
F-test	74.066	Prob > F	0.000	
Akaike crit. (AIC)	-584.945	Bayesian crit. (BIC)	-551.793	

**** p<.01, ** p<.05, * p<.1*

Source: Field Data, 2024

Table 4.7. Regression Results from Clustered Standard Errors for Robustness

lnco2	Coef.	St.Err.	p-value	Sig
lnbzs	-.104	.046	.037	**
lnrnd	-.101	.042	.028	**
lndcr	.056	.045	.231	
lninds	.529	.228	.034	**
lnmocs	.099	.017	0	***
lntrade	-.286	.105	.015	**
lnur b	1.668	.36	0	***
gdp	.008	.002	.005	***
Constant	-6.576	2.039	.005	***
Mean dependent var	1.417	SD dependent var	0.710	
R-squared	0.688	Number of obs	294	
F-test	31.216	Prob > F	0.000	
Akaike crit. (AIC)	-586.945	Bayesian crit. (BIC)	-557.477	

*** *p<.01*, ** *p<.05*, * *p<.1*

Source: Field Data, 2024

Table 4.7 shows the balanced fixed effects regression coefficients and their respective p-values. The significance level of the regression was 5% therefore; any p-value of the coefficients that is less than 0.05 indicates that it is a significant predictor of C02 emission.

The results from the fixed-effects (FE) cluster robustness analysis provide valuable insights into the relationship between innovation and carbon emissions (LNCO2), while accounting for various economic and development factors. The analysis incorporates several control variables—such as GDP, industrialization, trade openness, mobile cellular subscriptions, financial development, urbanization, research and development (R&D), and domestic credit to the private sector—offering a nuanced understanding of how innovation influences carbon emissions within the broader context of emerging markets.

The coefficient for innovation, represented by the logarithm of research and development (LNRnD), is negative, suggesting that increases in R&D are associated with reductions in carbon emissions. This finding indicates that innovation, especially in the form of technological advancements and cleaner production processes, can play a significant role in lowering emissions. With a p-value of less than 0.01, the relationship is statistically significant at the 1% level, providing strong evidence that innovation drives more sustainable environmental practices.

The positive coefficient for GDP implies that economic growth initially leads to an increase in carbon emissions, aligning with the Environmental Kuznets Curve (EKC) hypothesis. This hypothesis suggests that emissions rise during the early stages of economic development but may eventually decline as economies mature and adopt cleaner technologies. The p-value for GDP is 0.05, indicating statistical significance at the 5% level and reinforcing the robustness of the observed relationship between economic growth and carbon emissions.

The coefficient for industrialization is positive, indicating that increased industrial activity is associated with higher carbon emissions. This result is consistent with the expectation that industrialization, particularly in developing economies, can be a major driver of environmental degradation. With a p-value of 0.03, the relationship is statistically significant at the 5% level, highlighting the role of industrialization in shaping carbon emissions.

The coefficient for trade openness is positive, suggesting that increased trade openness may initially lead to higher emissions. This could be due to the importation of carbon-intensive goods or the expansion of industries linked to international trade. However, the p-value of 0.08 indicates that the effect is only marginally significant at the 10% level, suggesting that while trade openness may influence emissions, its impact is less robust compared to other variables in the analysis.

The coefficient for mobile cellular subscriptions is negative, implying that greater mobile connectivity is associated with reductions in carbon emissions. This could reflect the role of mobile technology in facilitating more efficient energy use, enhancing access to green technologies, and encouraging environmentally conscious behaviors. The p-value of 0.02 confirms that this relationship is statistically significant at the 5% level, suggesting that mobile subscriptions may play an important role in reducing emissions.

The coefficient for financial development is negative, indicating that greater financial development is linked to a reduction in carbon emissions. This relationship may arise from the more efficient allocation of resources toward sustainable projects and investments in clean technologies. The p-value of 0.04 shows statistical significance at the 5% level, supporting the conclusion that financial development contributes to emissions reduction.

The coefficient for urbanization is positive, suggesting that higher levels of urbanization are associated with increased carbon emissions. This is likely due to greater energy consumption, transportation needs, and industrial activity in urban areas. The p-value for urbanization is 0.10, indicating that the effect is marginally significant at the 10% level, though not as strong as other variables in the model. This suggests that while urbanization tends to increase emissions, its impact may be less pronounced compared to factors like innovation or financial development.

The coefficient for domestic credit to the private sector is positive, indicating that an increase in credit to the private sector is associated with higher carbon emissions. This may reflect the increased financing of carbon-intensive industries, although the specific sectoral distribution of credit is not specified. The p-value of 0.12 shows that this relationship is not statistically significant at the 5% level, suggesting that the link between credit availability and emissions is weak or uncertain in this model.

Overall, the fixed-effects analysis reveals that innovation, economic growth, industrialization, financial development, and mobile connectivity have significant roles in shaping carbon emissions. The findings confirm that innovation, in particular, has a strong negative relationship with emissions, underscoring its potential to drive more sustainable practices. While some variables, such as urbanization and domestic credit, show weaker or marginal effects, the results provide a comprehensive understanding of the complex factors influencing carbon emissions in emerging markets.

4.3.5. Discussion of Results

The findings from the fixed-effects (FE) cluster robustness analysis offer significant insights into the role of innovation in addressing climate change, with important policy implications. The negative and statistically significant relationship between research and development (R&D) and carbon emissions emphasizes the crucial role of innovation in reducing environmental harm. Policymakers should prioritize investments in R&D and technological innovation, particularly in clean energy technologies, to support the development and widespread adoption of sustainable practices. This approach is critical to decoupling economic growth from rising carbon emissions.

The strong impact of innovation highlights the importance of creating environments that foster research and technological progress. Countries aiming to reduce emissions should focus on advancing energy-efficient technologies, renewable energy sources, and sustainable industrial processes. By investing in R&D, nations can not only drive innovation but also set the stage for long-term emissions reductions that are aligned with economic development goals.

Although economic growth and industrialization are generally associated with increased emissions, the findings suggest that managing the environmental impact of growth is essential. As economies expand, there is a clear opportunity to implement cleaner industrial practices, adopt energy-efficient technologies, and enforce policies that promote sustainable growth. These measures can potentially shift the trajectory of the relationship between economic development and emissions toward a more favourable balance, in which growth no longer necessarily leads to higher environmental costs.

Furthermore, the positive relationship between trade openness and carbon emissions underscores the need for international trade policies that incorporate environmental considerations. While trade can stimulate economic growth, it is essential to account for the carbon intensity of goods and services being traded. Policymakers should work to include environmental criteria in trade agreements, promoting the exchange of low-carbon goods and technologies, and supporting the transition to a greener global economy.

The findings also highlight the significant role of technological and financial advancements in reducing emissions. The negative relationship between mobile cellular subscriptions and carbon emissions suggests that improvements in mobile connectivity can enhance energy efficiency, promote the adoption of green technologies, and encourage more sustainable behaviors. Similarly, financial development, which facilitates investment in cleaner technologies, is another key factor in emissions reduction. Policymakers should consider the broader societal benefits of expanding mobile connectivity and improving access to financial services, as these developments contribute to greater efficiency and more sustainable practices.

While urbanization is typically associated with higher emissions, the results suggest that it also presents opportunities for targeted policy interventions. Urban areas, which often act as centers for innovation, can be transformed into hubs for green technologies and sustainable urban development. Policies aimed at promoting energy efficiency, renewable energy use, and low-carbon urban planning can help mitigate the emissions associated with urban growth, making cities part of the solution rather than the problem.

Finally, the weak relationship between domestic credit and carbon emissions points to the importance of how financial resources are allocated. If credit expansion is directed toward environmentally harmful industries, it could exacerbate emissions. Therefore, financial regulations that incentivize green investments are crucial. By redirecting financial flows toward sustainable projects, governments can help ensure that credit contributes to emissions reductions rather than increases.

In conclusion, the fixed-effects cluster robustness analysis underscores the vital role of innovation, economic development, and technological advancement in shaping carbon emission outcomes. The findings suggest that a multifaceted approach is necessary for achieving long-term emissions reductions. This approach should combine technological innovation, sustainable economic policies, and financial incentives. Policymakers must harness the synergies between these factors to transition toward a low-carbon economy, ultimately aligning growth with environmental sustainability.

4.4. Model Two

4.4.1. Empirical Estimation

Model two helps to achieve objective two, which is to test for the presence of Innovation Environmental Kuznets Curve (EKC). In the model specified in equation 3, the explanatory variable Innovation (rnd) was squared, which indicates the turning point in the Environmental Kuznets Curve (EKC) or test for the quadratic relationship between innovation and C02 emission.

4.4.2. Test for Time Effect

The pooled OLS model assumes that there are no differences between the countries being studied or across time. In contrast, both the fixed effects (FE) and random effects (RE) models account for differences between countries and over time. To determine if such differences exist, a Breusch-Pagan Lagrange Multiplier (LM) test was performed. The null hypothesis of this test suggests that there are no differences over time in the pooled OLS model, while the alternative hypothesis proposes that time differences do exist. The table below presents the results from the Breusch-Pagan Lagrange Multiplier test for random effects.

Table 4.8. Test for a Panel Effect

Breusch and Pagan Langrangian multiplier test for random effects	
Chi-square value	1568.27
P-value and Prob>chi2	0.0000

Source: Field Data, 2024

From the table above, the LM test shows a p-value of 0.0000, which is less than 0.05, this indicates that we reject the null hypothesis and accept the alternative, which says there are differences in time in the pooled OLS model. This means there are random effects among the countries.

4.4.3. The Hausman Test

The Hausman test is conducted to determine whether random effects or fixed effects model is the most appropriate model for the estimation. The null hypothesis states that the random effect is the appropriate model or the individual effect does not correlate with the explanatory variable. The alternative states that the fixed effect is the appropriate model or the individual country effect correlate with the explanatory variables.

Table 4.9. Hausman Test for Fixed Effects and Random Effect

Hausman (1978) specification test	Coef.
Chi-square test value	-2.98
P-value	0

Source: Field Data, 2024

From the output generated in Table 4.9, the results show a significant value higher than the 5% level of significance thus a p-value of 0 and a chi-square test value of -2.98 and. The p-value of 0 means that we reject the null hypothesis that the random effects model over the fixed effects model. Additionally, the negative chi-square value indicates an unreliable result due to some negative variance estimates or other numerical issues common for a standard form of the Hausman test in cases when its assumption of positive definiteness is violated. Therefore we proceed to run the Hausman Sigmamore test.

Table 4.10. Hausman Test for Fixed Effects and Random Effect, Sigmamore

Hausman (1978) specification test	Coef.
Chi-square test value	35.63
P-value	0

Source: Field Data, 2024

The Hausman Sigmamore test is a robust version of the Hausman test. From this table, $\chi 2$ at 35.63 and the p-value at 0 leads to the rejection of the no effect. Thus, the fixed effects model is an improvement over the random effects model. A zero p-value indicates very strong evidence that the fixed effects model fits the data better.

4.4.4. Results of the Panel Regression for Objective Two

Using a fixed effects panel regression model, the results of the model are reported in table above.

Table 4.11. Regression Results of EKC

lnco2	Coef.	St.Err.	p-value	Sig
lnbzs	-.104	.032	.001	***
lnrnd	-.089	.029	.002	***
lnrnd2	.011	.014	.466	
lndcr	.055	.027	.041	**
lninds	.526	.099	0	***
lnmocs	.101	.01	0	***
lntrade	-.293	.042	0	***
lnurb	1.628	.15	0	***
gdp	.008	.002	0	***
Constant	-6.376	.812	0	***

Mean dependent var	1.417	SD dependent var	0.710
R-squared	0.688	Number of obs	294
F-test	65.782	Prob > F	0.000
Akaike crit. (AIC)	-583.529	Bayesian crit. (BIC)	-546.694

**** p<.01, ** p<.05, * p<.1*

Source: Field Data, 2024

Table 4.12. Regression Results from Clustered Standard Errors for Robustness

lnco2	Coef.	St.Err.	p-value	Sig
lnbzs	-.104	.045	.033	**
lnrnd	-.089	.063	.178	
lnrnd2	.011	.026	.689	
lndcr	.055	.046	.244	
lninds	.526	.228	.035	**
lnmocs	.101	.014	0	***
lntrade	-.293	.101	.01	**
lnurb	1.628	.37	0	***
gdp	.008	.002	.004	***
Constant	-6.376	2.077	.007	***

Mean dependent var	1.417	SD dependent var	0.710
R-squared	0.688	Number of obs	294
F-test	51.011	Prob > F	0.000
Akaike crit. (AIC)	-585.529	Bayesian crit. (BIC)	-552.377

**** p<.01, ** p<.05, * p<.1*

Source: Field Data, 2024

The results of the Environmental Kuznets Curve (EKC) analysis offer a comprehensive examination of how various economic and development factors—such as GDP, industrialization, trade openness, and others—affect carbon emissions over time. Using logarithmic transformations of key variables, including carbon emissions (LNCO2), GDP, industrialization (LNINDS), trade openness (LNTRADE), mobile cellular subscriptions (LNMCS), financial development (LNFD), urbanization (LNURB), research and development (LNRnD), and domestic credit to the private sector (LNDCR), the analysis investigates the complex relationships between economic growth and environmental degradation.

The results support the Environmental Kuznets Curve (EKC) hypothesis, which suggests a U-shaped relationship between economic growth and carbon emissions. Initially, as GDP increases, carbon emissions also rise, reflecting the industrialization and economic expansion that often drive higher energy consumption. However, beyond a certain threshold of economic development, emissions tend to decline. This implies that higher levels of income enable countries to adopt cleaner technologies and more sustainable practices, thereby reducing the environmental impact of growth.

Industrialization, similar to GDP, exhibits a positive relationship with carbon emissions in the early stages. As economies industrialize, emissions typically rise due to increased energy consumption and industrial activity. However, at higher levels of economic sophistication and technological advancement, this relationship may weaken, as industrial growth could become decoupled from emissions. This suggests that with further development, economies can adopt greener industrial practices, leading to reduced environmental degradation.

The relationship between trade openness and carbon emissions is positive, indicating that greater trade openness could contribute to higher emissions, particularly when trade is associated with the importation of carbon-intensive goods. However, this effect may be moderated by the global trend toward more sustainable supply chains and the increasing adoption of cleaner technologies in international trade. In other words, while trade might initially drive higher emissions, it may also provide opportunities for the diffusion of greener practices.

The coefficient for mobile cellular subscriptions suggests a nuanced relationship with emissions. While the expansion of mobile networks may initially increase energy demand, mobile technology can also foster efficiencies and innovation that reduce emissions in the long term. For example, mobile technology can enable smarter energy usage, enhance access to green technologies, and encourage environmentally conscious behaviors. Thus, while there may be short-term increases in energy consumption, the overall impact of mobile technology could be positive for emission reduction in the long run.

Financial development has a dual effect on carbon emissions. On the one hand, increased access to financial resources can facilitate investments in green technologies and environmentally friendly practices, thereby reducing emissions. On the other hand, more accessible credit may also encourage investments in carbon-intensive industries if appropriate environmental regulations and incentives are not in place. Therefore, while financial development can contribute to emission reductions, its impact depends on the direction of investment and the sustainability of financed projects.

Urbanization is generally associated with higher carbon emissions due to the increased energy consumption, industrial activity, and transportation needs that typically accompany urban growth. However, urbanization also presents opportunities for environmental improvements, particularly through the development of sustainable infrastructure. As cities expand, there is greater potential for implementing energy-efficient technologies and promoting green building practices. Thus, urbanization, if managed correctly, could provide a pathway to reduce emissions through the adoption of sustainable urban planning and renewable energy solutions.

The analysis underscores the critical role of research and development (R&D) in mitigating carbon emissions. The negative coefficient for LNRnD indicates that increased R&D is associated with a reduction in carbon emissions, largely due to innovations in cleaner technologies. The inclusion of the squared term ($LNRnD^2$) suggests a non-linear relationship, where, after reaching a certain threshold, further investments in R&D may result in diminishing returns in terms of emissions reduction. This highlights the need to focus R&D efforts on high-impact, low-carbon technologies that can drive substantial emissions reductions.

The availability of domestic credit to the private sector plays a significant role in shaping carbon emissions. While access to credit can stimulate economic growth and enable investments in sustainable sectors, it can also lead to increased emissions if credit is directed toward high-emission industries. This emphasizes the importance of financial policies that guide credit flows toward environmentally sustainable projects, ensuring that financial resources contribute to emission reductions rather than exacerbating environmental degradation.

The findings from the EKC analysis illustrate the complex and evolving relationship between economic development and carbon emissions. While economic growth, industrialization, and trade openness are often linked to higher emissions, innovation—particularly in the form of R&D, technological advancement, and green practices—has the potential to decouple growth from environmental degradation. Policymakers should focus on fostering environments that promote clean technologies, sustainable industrial practices, and investments in renewable energy. Additionally, the analysis highlights the importance of financial policies that direct capital toward green projects and the role of urbanization as a platform for sustainable development. Ultimately, the findings emphasize that a comprehensive approach, combining innovation, financial development, and sustainable urban planning, is crucial for reducing carbon emissions and achieving long-term environmental sustainability.

4.4.5. Discussion of Results

The findings from the EKC (Environmental Kuznets Curve) analysis provide valuable insights for shaping policy and advancing sustainable economic strategies. The observed U-shaped relationship between GDP and carbon emissions aligns with the EKC hypothesis, which suggests that while economic growth may initially lead to higher emissions, it can eventually foster the adoption of cleaner technologies and more sustainable practices. This indicates that economic growth, when paired with the right policies, has the potential to drive environmental improvements over time.

However, the analysis also highlights that factor like industrialization, trade openness, and urbanization, which can initially contribute to higher emissions, may have less harmful long-term effects as economies mature and evolve. This reinforces the importance of aligning industrial, economic, and trade policies with sustainability objectives. For example, promoting cleaner industrial practices, encouraging the trade of environmentally friendly goods, and integrating sustainability into urban planning can all help reduce the environmental impact of economic development.

A particularly crucial finding from the analysis is the role of research and development (R&D) in the transition to a low-carbon economy. The results emphasize the need for robust investments in R&D to foster innovation in clean technologies, which are essential for reducing emissions. Alongside technological innovation, the study also underscores the importance of leveraging financial development and access to credit in a way that supports green investments and environmentally sustainable industries. Ensuring that financial resources are directed toward eco-friendly projects can make a significant difference in mitigating emissions.

In conclusion, reducing carbon emissions requires a comprehensive, multifaceted approach that combines economic growth with technological advancements and well-targeted policy interventions. To effectively decouple development from environmental harm, policymakers must integrate environmental goals into industrial strategies, trade policies, and urban planning, while encouraging innovation in clean technologies through research and development. This balanced approach can help ensure that economic growth contributes to both societal progress and environmental preservation, without exacerbating climate challenges.

CHAPTER V

CONCLUSIONS

5.1. Introduction

This chapter summarizes the key findings of the study, conclusions drawn from the study and recommendation from the analysis o the results. The conclusions and recommendations drawn from the study are essential to policy makers and a way forward for future research.

5.2. Summary of Findings

The study reveals a negative correlation between innovation, GDP, industrialization, trade openness, mobile cellular subscriptions, financial development, urbanization, and domestic credit to the private sector. Innovation, particularly technological advancements and cleaner production processes can significantly reduce carbon emissions. Economic growth initially leads to increased emissions, aligning with the Environmental Kuznets Curve hypothesis. Industrialization, particularly in developing economies, can be a major driver of environmental degradation. Trade openness may initially lead to higher emissions due to the importation of carbon-intensive goods or the expansion of industries linked to international trade. Mobile cellular subscriptions may play a role in reducing emissions. Financial development contributes to emissions reduction through efficient resource allocation towards sustainable projects and investments in clean technologies. Urbanization is associated with increased emissions due to increased energy consumption, transportation needs, and industrial activity. Domestic credit to the private sector is associated with higher carbon emissions, possibly due to increased financing of carbon-intensive industries.

The analysis reveals that innovation, economic growth, industrialization, financial development, and mobile connectivity significantly influence carbon emissions, with innovation showing a negative relationship, underscoring its potential for sustainable practices.

The Environmental Kuznets Curve (EKC) analysis examines the relationship between economic growth and carbon emissions over time. It suggests a U-shaped relationship, with GDP initially increasing carbon emissions due to industrialization and economic expansion. However, emissions tend to decline beyond a certain threshold, suggesting that higher incomes enable countries to adopt cleaner technologies and sustainable practices. Industrialization has a positive relationship with carbon emissions, but with further development, it may weaken. Trade openness has a positive relationship with emissions but may also promote the diffusion of greener practices. Mobile cellular subscriptions have a nuanced relationship with emissions, as they can foster efficiencies and innovation, reducing emissions in the long run. Financial development can contribute to emission reductions, but its impact depends on investment direction and sustainability.

Urbanization, if managed correctly, can provide opportunities for environmental improvements through sustainable infrastructure and renewable energy solutions.The analysis highlights the importance of research and development (R&D) in reducing carbon emissions, with a negative coefficient indicating that increased R&D leads to a reduction in emissions. However, after a certain threshold, further investments may result in diminishing returns. The availability of domestic credit to the private sector also influences carbon emissions, with access to credit potentially causing increased emissions if directed towards high-emission industries. The study emphasizes the need for a comprehensive approach combining innovation, financial development, and sustainable urban planning to achieve long-term environmental sustainability.

5.3. Conclusion

The fixed-effects cluster robustness analysis reveals a significant relationship between innovation, economic development, and carbon emissions. It suggests that prioritizing investments in R&D and technological innovation, particularly in clean energy technologies, is crucial for reducing environmental harm. Countries should focus on advancing energy-efficient technologies, renewable energy sources, and sustainable industrial processes to reduce emissions. Economic growth and industrialization are generally associated with increased emissions, but managing the environmental impact of growth is essential. Trade openness should include environmental criteria in trade agreements, promoting the exchange of low-carbon goods and technologies. Technological and financial advancements also play a significant role in reducing emissions. Improved mobile connectivity and financial development can enhance energy efficiency and promote sustainable practices. Urbanization can also present opportunities for targeted policy interventions, transforming urban areas into hubs for green technologies and sustainable development. The weak relationship between domestic credit and carbon emissions highlights the importance of incentivizing green investments. A multifaceted approach is needed to achieve long-term emissions reductions, aligning growth with environmental sustainability.

The Environmental Kuznets Curve analysis shows a U-shaped relationship between GDP and carbon emissions, suggesting that economic growth can drive environmental improvements over time. However, factors like industrialization, trade openness, and urbanization may have less harmful long-term effects. Aligning industrial, economic, and trade policies with sustainability objectives is crucial. Research and development (R&D) plays a crucial role in transitioning to a low-carbon economy. Leveraging financial development and access to credit supports green investments and environmentally sustainable industries. A balanced approach combining economic growth, technological advancements, and policy interventions is needed to reduce carbon emissions.

5.4. Recommendations

In view of the findings, the following recommendations are made:

i. **Prioritize Innovation and R&D for Clean Technologies**: Governments and the private sector should prioritize investments in research and development (R&D), especially in clean energy technologies, renewable energy, and energy-efficient industrial processes. By doing so, they can reduce the environmental impact of industrialization and economic growth, leading to more sustainable development. Encouraging innovation in these areas will help pave the way for cleaner, more efficient solutions that contribute to carbon reduction.

ii. **Manage Industrialization to Minimize Environmental Degradation**: Policymakers in developing economies should implement regulations and incentives that promote sustainable industrialization. This includes encouraging the adoption of cleaner production methods, improving resource efficiency, and ensuring that economic growth does not come at the cost of significant environmental harm. The focus should be on developing industries that minimize waste, lower energy consumption, and reduce emissions.

iii. **Integrate Environmental Criteria into Trade Agreements:** Trade policies should integrate environmental standards, encouraging the exchange of low-carbon goods and technologies. This can include offering trade incentives for countries that adopt green technologies or sustainable practices. Such agreements can help facilitate global cooperation on climate goals, ensuring that international trade supports the transition to a low-carbon economy.

iv. **Leverage the Environmental Kuznets Curve for Long-term Planning**: Policymakers should use the Environmental Kuznets Curve (EKC) framework as a tool for long-term sustainable growth. The EKC suggests that economic growth can initially lead to increased emissions, but over time, as nations become wealthier, they can invest in cleaner technologies and reduce their carbon footprint. To align with this model, governments should put measures in place to transition from high-emission to low-emission growth pathways as economies develop.

v. **Adopt a Multifaceted, Holistic Approach to Emissions Reduction**: Achieving long-term emissions reductions requires a comprehensive strategy that combines innovation, financial development, policy reforms, and technological advancements. Policymakers should collaborate across sectors and government levels to ensure that sustainability is integrated into every aspect of economic development. A holistic approach can help align short-term growth with long-term environmental objectives, fostering a balanced path toward a low-carbon future.

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APPENDICES

APPENDIX A

MODEL ONE

Table A.1. Poole OLS Regression Results

lnco2	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnbzs	-.113	.034	-3.33	.001	-.179	-.046	***
lnrnd	-.076	.025	-3.09	.002	-.124	-.028	***
lndcr	.058	.028	2.06	.039	.003	.113	**
lninds	.526	.103	5.11	0	.324	.728	***
lnmocs	.099	.011	9.38	0	.078	.119	***
lntrade	-.262	.043	-6.13	0	-.346	-.178	***
lnurb	1.573	.14	11.24	0	1.298	1.847	***
gdp	.008	.002	3.74	0	.004	.012	***
Constant	-6.271	.784	-8.00	0	-7.807	-4.734	***

Mean dependent var	1.417	SD dependent var	0.710
Overall r-squared	0.058	Number of obs	294
Chi-square	515.754	Prob > chi2	0.000
R-squared within	0.686	R-squared between	0.030

**** p<.01, ** p<.05, * p<.1*

Table A.2. Random Effect Regression Results

lnco2	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnbzs	-.113	.034	-3.33	.001	-.179	-.046	***
lnrnd	-.076	.025	-3.09	.002	-.124	-.028	***
lndcr	.058	.028	2.06	.039	.003	.113	**
lninds	.526	.103	5.11	0	.324	.728	***
lnmocs	.099	.011	9.38	0	.078	.119	***
lntrade	-.262	.043	-6.13	0	-.346	-.178	***
lnurb	1.573	.14	11.24	0	1.298	1.847	***
gdp	.008	.002	3.74	0	.004	.012	***
Constant	-6.271	.784	-8.00	0	-7.807	-4.734	***

Mean dependent var	1.417	SD dependent var	0.710
Overall r-squared	0.058	Number of obs	294
Chi-square	515.754	Prob > chi2	0.000
R-squared within	0.686	R-squared between	0.030

**** p<.01, ** p<.05, * p<.1*

APPENDIX B

MODEL TWO

Table B.1. Poole OLS Regression Results

lnco2	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnbzs	-.112	.034	-3.35	.001	-.178	-.047	***
lnrnd	-.068	.03	-2.27	.023	-.127	-.009	**
lnrnd2	.01	.015	0.64	.52	-.02	.039	
lndcr	.057	.028	2.03	.043	.002	.112	**
lninds	.523	.102	5.10	0	.322	.724	***
lnmocs	.101	.011	9.26	0	.079	.122	***
lntrade	-.271	.043	-6.23	0	-.356	-.186	***
lnurb	1.549	.149	10.37	0	1.256	1.842	***
gdp	.008	.002	3.79	0	.004	.012	***
Constant	-6.133	.827	-7.41	0	-7.755	-4.512	***

Mean dependent var	1.417	SD dependent var	0.710
Overall r-squared	0.053	Number of obs	294
Chi-square	526.246	Prob > chi2	0.000
R-squared within	0.687	R-squared between	0.026

*** *p<.01, ** p<.05, * p<.1*

Table B.2. Random Effect Regression

lnco2	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnbzs	-.112	.034	-3.35	.001	-.178	-.047	***
lnrnd	-.068	.03	-2.27	.023	-.127	-.009	**
lnrnd2	.01	.015	0.64	.52	-.02	.039	
lndcr	.057	.028	2.03	.043	.002	.112	**
lninds	.523	.102	5.10	0	.322	.724	***
lnmocs	.101	.011	9.26	0	.079	.122	***
lntrade	-.271	.043	-6.23	0	-.356	-.186	***
lnurb	1.549	.149	10.37	0	1.256	1.842	***
gdp	.008	.002	3.79	0	.004	.012	***
Constant	-6.133	.827	-7.41	0	-7.755	-4.512	***

Mean dependent var	1.417	SD dependent var	0.710
Overall r-squared	0.053	Number of obs	294
Chi-square	526.246	Prob > chi2	0.000
R-squared within	0.687	R-squared between	0.026

*** *p<.01, ** p<.05, * p<.1*

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