NEAR EAST UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF ECONOMICS

COMPARATIVE ANALYSIS ON THE ROLE OF ENERGY CONSUMPTION, TECHNOLOGICAL PROGRESS, NATURAL RESOURCES, AND GOVERNMENT EFFECTIVENESS ON CARBON EMISSION FOR HIGH AND LOW-EMITTING ECONOMIES.

M.Sc. THESIS

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Nicosia

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Declaration

I hereby declare that all information, documents, analysis, and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of the Institute of Graduate Studies, Near East University. As required by these rules and conduct, I also declare that I have fully cited and referenced information and data that are not original to this study.

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Abstract

"Comparative Analysis on the Role of Energy Consumption, Technological Progress, Natural Resources, and Government Effectiveness on Carbon Emission for High and Low-Emitting Economies"

Christiana Chioma Efe-Onakpojeruo (20227178)
Master in Economics.
June, 2024 (230)

This research study performs an extensive comparative analysis of the relationship between GDP (gross domestic product) per capita, renewable energy (RE) adoption, fossil fuel (FF) energy consumption, patent application (PTS), natural resources rents (NRR), government effectiveness (GE), and CO_2 emissions in economies with high CO_2 emissions and low CO_2 emissions. The major objective is to grasp the key drivers of CO_2 emissions for these economies that differ in terms of their levels of economic development, energy use patterns, innovation opportunities, natural resources availability, and governance effectiveness. the method of moments quantile regression is employed for data analysis with the purpose of investigating the relationships among those variables. The early research highlights the complicated interplay among GDP per capita, renewable energy adoption, fossil fuel energy consumption, patent application, natural resources, government effectiveness, and CO_2 emissions in this economics. High-emitted economies are associated with elevated CO_2 emissions because of the fast industrialization process and the increase in energy demand whereas low-emitted economies have emissions lower because of the extensive renewable energy sources, efficient resource utilization, and good governance. The study contributes to a deepening knowledge of factors behind CO_2 emissions and the policymakers, researchers, and practitioners can use the information to control the emissions level and take mitigation actions towards sustainable development. Because they examine CO_2-related issues in depth, they can advise about specific actions to be taken that tailor individual and structural situations.

Keywords: energy consumption, technological progress, natural resources, government effectiveness, carbon emission, GDP per capita.

Soyut

“Yüksek ve Düşük Salınım Yapan Ekonomiler için Enerji Tüketimi, Teknolojik İlerleme, Doğal Kaynaklar ve Karbon Emisyonunda Devlet Etkinliğinin Rolü Üzerine Karşılaştırmalı Analiz”

Christiana Chioma Efe-Onakpojeruo (20227178)
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Bu araştırma çalışması, kişi başına düşen GSYİH (gayri safi yurtiçi hasıla), yenilenebilir enerjinin (YE) benimsenmesi, fosil yakıt (FF) enerji tüketimi, patent başvurusu (PTS), doğal kaynak kiraları (NRR), hükümet arasındaki ilişkinin kapsamlı bir karşılaştırmalı analizini gerçekleştirmektedir. CO2 emisyonları yüksek ve CO2 emisyonları düşük olan ekonomilerde etkinlik (GE) ve CO2 emisyonları. Temel amaç, ekonomik kalkınma düzeyleri, enerji kullanım modelleri, yenilik fırsatları, doğal kaynakların mevcudiyeti ve yönetişim etkinliği açısından farklılık gösteren bu ekonomiler için CO2 emisyonlarının temel etkenlerini kavramaktır. Bu değişkenler arasındaki ilişkileri araştırmak amacıyla veri analizi için momentler kantil regresyon yöntemi kullanılır. İlk araştırmalar, bu ekonomide kişi başına düşen GSYİH, yenilenebilir enerjinin benimsenmesi, fosil yakıt enerji tüketimi, patent başvurusu, doğal kaynaklar, hükümet etkinliği ve CO2 emisyonları arasındaki karmaşık etkileşimi vurgulamaktadır. Yüksek emisyonlu ekonomiler, hızlı sanayileşme süreci ve enerji talebindeki artış nedeniyle yüksek CO2 emisyonlarıyla ilişkilendirilirken, düşük emisyonlu ekonomiler, kapsamlı yenilenebilir enerji kaynakları, verimli kaynak kullanımı ve iyi yönetişim nedeniyle daha düşük emisyonlara sahiptir. Çalışma, CO2 emisyonlarının ardındaki faktörlere ilişkin bilginin derinleşmesine katkıda bulunuyor ve politika yapıcılar, araştırmacılar ve uygulayıcılar bu bilgiyi emisyon seviyesini kontrol etmek ve sürdürülebilir kalkınmaya yönelik azaltım önlemleri almak için kullanabilirler. CO2 ile ilgili konuları derinlemesine inceledikleri için, bireysel ve yapısal durumlara uygun olarak alınması gereken spesifik eylemler hakkında tavsiyelerde bulunabilirler.

Anahtar Kelimeler: enerji tüketimi, teknolojik ilerleme, doğal kaynaklar, hükümet etkinliği, karbon emisyonu, Kişi başına düşen GSYİH.

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Abbreviation

AMG-Augmented Mean Group

ARDL-Autoregressive Distributed Lag

BRI-Belt and Road Initiative

BRICS COUNTRIES -Brazil, Russia, India, China, South Africa.

CCEMG-Common Correlated Effect Mean Group

CO_2-Carbon Oxides Emissions

DOLS-Dynamic Ordinary Least Square

E7-Emerging Seven

EKC-Environmental Kuznets Curve

EU-European Union

FDI- Foreign Direct Investment

FE-OLS- Fixed-Effects Ordinary Least Square

FF-Fossil Fuel

FMOLS-Fully Modified Ordinary Least Square

GDP-Growth-Economic Growth

GDP PER CAPITA-Gross Domestic Product Per Capita

GE-Government Effectiveness

GFCF- Gross Fixed Capital Formation

GMM-Generalized Method of Moments

IPCC -Intergovernmental Panel on Climate Change

MARS -Motivation, Ability, Role Perception, and Situational Factors Model

MINT COUNTIES- Mexico, Indonesia, Nigeria, Turkey

MMQR- Method of Moments Quantile Regression

NRR-Natural Recourses Rents

PTS-Patient Applications

RE-Renewable Energy

SSA- Sub-Saharan African

STIRPAT-Stochastic Impacts by Regression on Population, Affluence, And Technology

TIS-Technological Innovation Systems

VECM-Vector Error Correction Model

WB – World Bank

CHAPTER 1

Introduction

1. Background

The world experienced an outstanding economic growth accompanied with rapid industrialization in the last few years, which resulted in the increased level of energy use and releases of carbon dioxide (Usman et al., 2022; Warr et al., 2010). Since from now, the key questions to be figured out are: whether the current development patterns are sustainable in the long run and would impose a huge impact on climate change (A. Banerjee et al., 2024; Bradshaw et al., 2024). The problem of searching for a balance between economic growth and environmental responsibility becomes more serious due to the fact that prosperous and wealthy countries are putting their efforts into enhancing their national economies and the welfare of people (W. Azam et al., 2023a). Added to that, urbanization, population growth, and industrialization are principal factors for current developing countries to become crucial players in the global economy (Rubaj, 2023). The economic growth of such countries as Brazil, Russia, China, and India has been a stimulus behind their demands for energy and raw material sources (Elalouf, 2023; T. Li et al., 2023). The case of expansion does not come out as simple as that since growing amounts of CO_2 in the air are the cause of both the global warming and the pollution of our planet in general (L. J. Liu et al., 2023). However, some other developing economies have instead opted for different routes of development that focus more on the preservation of the environment while at the same time fostering balance and sustainability in their economic activities such as Sweden, Norway, New Zealand, Costa Rica, and Switzerland (Skare et al., 2024). The development process of these countries includes a focus on green technology adoption, water and air pollution control, as well as the use of green and RE which is not only aimed at decreasing carbon footprint but also at environmental resiliency(Ikram et al., 2021). Industrialization, urbanization and technological growth that are some of the key features characterizing the current-world-economy (Raihan, 2023). The recent epoch of heightened economic growth resulted in revolutionary production processes, the way of life, and energy use. As a consequence, greenhouse gas emissions giving dominance to CO_2 have shown a big rise; thus, the issue of sustainable development and climate change is very alarming.

The framework of this research is linked to the wider issues of global ecological impact and the role of the global economy in it (M. Ahmad et al., 2020a). In the last decade and a half, there has been tremendous growth in the global economy which is mainly attributable to emerging economies like India, Brazil, China, and Russia (Siddiqui, 2020). These countries are now following the typical pattern of rapid industrialization and urbanization, resulting in more energy consumption that is dominated by the use of FF among others (B. Li & Haneklaus, 2021). Moreover, one of the world's very serious issues, which is climate change, has been also tackled by them (Murunga et al., 2024). The dreadful consequence is waves of sea level rise, evaporation of ice caps, temperature increase, and extreme weather events due to the greenhouse gases, especially CO_2, concentration in the earth's atmosphere (Hansen et al., 2016). The Intergovernmental Panel on Climate Change (IPCC) has released many reports on the other long-term impacts of uncontrolled change in climate such as migration, extinction of animal species, and threats to water and food supplies (Ndubisi, n.d.).

For a better understanding of the current situation, consideration of the historical elements that affected the economic and ecological development paths should be assessed (Blinova et al., 2022) The fact that energy consumption and the emission of CO_2 had an increasing correlation with the rise in industrialization and the development of the economy is an important point in history (Rehman, Ma, & Ozturk, 2021). The Industrial Revolution which started somewhere during the 18th century closing was a historical turning point in human life. In this history lies a transition from agricultural economies to manufacturing-driven countries by the use of coal, oil, and gas. The period after World War II was characterized by a high growth of the economy and new technological development, which became a crucial part of the new consumer societies' appearance and the development of the international market. During this period of time, the so-called "carbon economy," which was based on the domination of FF being the main energy source for transportation, manufacturing, and electrical power generation was developing (Kabeyi & Olanrewaju, 2022). With the widespread use of FF, economic development was unlocked, but the unparalleled production of carbon dioxide because of this also contributed to the worsening of climate change (Singh, 2021).

The existence of emerging and developed economies indicates therefore the multifaceted interactions between economic development, energy sources, innovation and technology advancements, and environmental conservation.(F. Wang et al., 2023). Notwithstanding the fact that earlier scholars have explored different aspects of this complicated issue, there is still a major shortage of a detailed comparative study covering multiple economies and long periods. This study will address this research gap by carrying out longitudinal research that covers the period from 1990 to 2020. The empirical research will concentrate on key determinants such as GDP per capita, use of RE sources, FF usage, PTS, NRR, GE, and CO_2 emissions in ten selected economies. This research will investigate the interactions and relationships between socioeconomic and environmental consequences through an extensive literature review of economics, environmental sciences, energy studies, and innovation studies.

The quest for sustainable development has emerged as one of the significant tasks of the 21st century, as we endeavor to harmonize economic growth, environmental protection, and social equity. (Sungkawati, 2024). This technique indeed, which seeks is to meet the needs of the current generation while ensuring those in the future have an equal amount of space and resources, gives an idea that there should be a harmonious and all-round approach to development. The focal point of discussions on sustainable development revolves around two things: the development and emerging pathways in the economies of developing and newly developing nations, which are faced with a range of complex socioeconomic and environmental factors (Bowen et al., 2017; Negi, 2024). Most emerging economies worldwide, including those in the USA, Brazil, Russia, China, and India remain positive upon the process of industrialization and urbanization. Upon the attainment of these markets, the economies of the countries have witnessed tremendous growth in their GDP per capita and energy consumption, as these nations basically are fossil fuel dependent. And yet, these countries' expansions have had a consequential effect on climate, having them become larger emitters of CO_2 into the atmosphere. They now have a variety of problems to deal with, like smog, over-exploitation, and global warming among which they are the most concerned. While on this, there are other developing countries which have proven many in the world wrong that a country can deliver sustainable development as is the example of Sweden, Norway, Switzerland, New Zealand, and Costa Rica. These countries have focused on increasing the use of renewable energy, enacting progressive legislation related to the environment, and promoting sustainable cultures at the policies — all of these while having much lower GDP per capita than their contestants with developing economies. Environment-friendly actions become vivid because of their good work that is revealed through excellent conservation efforts and low CO_2 emissions. Through a three-decade longitudinal research, the study aims to shed light on the opportunities, challenges, and factors that influence sustainable development in rising and developing countries. Utilizing an extensive array of literature from disciplines like economics, environmental science, energy studies, and innovation research, the thesis seeks to illuminate the intricate relationships and feedback loops that influence socio-economic and environmental consequences. The research holds great importance as it has the ability to enhance knowledge and provide valuable insights for evidence-based policymaking initiatives that aim to promote equitable and environmentally sustainable growth paths globally.

This study aims to enhance the capabilities of policymakers, stakeholders, and researchers in their pursuit of a sustainable and equitable future through the provision of empirical facts, theoretical insights, and actionable recommendations.

The study undertakes an extensive examination of the various dimensions of sustainable development challenges and opportunities in these economies. Its main goal is to create knowledge that can help in making this contribution and make major improvements in the global environment well-being that can be a shared responsibility of the entire society (present and future generations).

Moreover, the survey published by British Petroleum on the 2018 statistical review of the world energy revealed that CO_2 emissions had risen by 29,714. 2 to 33,444. 0 million tons of e-waste was generated during the years of 2009-2017. As for the economic growth of the United States, CO_2 per capita emission of the environment has increased from 0. 04 to 16. The burning of 16t of coal during the period of 1800 to 2017. As the annual CO_2 emissions increased on the same level in the USA, the total carbon dioxide of the region also increased from 267472 to 5.28 billion tons in 2019.

The evaluation of carbon emission and environment sustainability is not something that can be overlooked and it is very important to determine the role that NRR could play in this evaluation. Countries with ample endowment in natural resources should be wealthier and raise economic development than the countries with fewer resources and capitals (S. Z. Huang et al., 2020; Ncube et al., 2020; Umar, Ji, Kirikkaleli, & Xu, 2020). Though, there is an opinion that some countries that are endowed with natural resources have worse situations in income inequality, poverty, and civil litigations as compared to other countries that have few or no natural resource wealth. Thus, the prevalence of the question of how the richness of NR determines GDP growth interests both researchers and policymakers. However, the overall positive or negative contribution of NRR on environmental sustainability especially on CO_2 emissions is still in debate in the literature currently under publication. This is due to the fact that literature on the effects of economic growth on natural resources has been a longstanding one starting as early as the seventeenth century (He et al., 2018; Kennedy et al., 2020; Odugbesan & Rjoub, 2020)

Based on a study, by (Danish, Baloch, & Wang, 2019)). Governance comprises six elements; corruption, government effectiveness, quality (regularity quality), political stability, rule of law, voice, and accountability. Governance plays a role, in deterioration well. The governmental framework and the strength of institutions influence the environmental condition either directly or indirectly. By facilitating greater equity in the allocation of power and income, institutional quality contributes to the improvement of the environment and lower levels of pollution (S. T. Hassan et al., 2020). Government regulation of emission levels is made possible by a strong institutional framework, and institutional quality plays a critical role in reducing pollution levels through democracy and the control of corruption, which in turn helps to better design government policies for pollution reduction (H. M. Hosseini & Kaneko, 2013a)). A structure for governance that helps mitigate the impact of market imperfections, for instance, is one that upholds the rule of law, has an effective legal system, and protects property rights. Pollution levels can be reduced with reluctance to abide by environmental regulations by the efficient regulation of environmental measures. If not, regulations would include gaps that would make it difficult to implement laws to lower CO_2 emissions (Abid, 2016a)). Corruption in the environmental sector is made possible by governance flaws, which can have a direct or indirect impact on environmental stress (Socioeconomics & 2016, 2016)). According to (Goel et al., 2013)). In the context of CO_2 emissions' impact on the repression of corruption and the shadow economy, institutional quality is yet another crucial element of governance. Although environmental policies that are influenced by corruption may exacerbate environmental stress, measures to combat corruption attenuate and lessen the correlation between GDP and CO_2 levels, indirectly lowering pollution levels. Furthermore, corruption directly affects CO_2 emissions, which in turn causes pollution since it is more expensive politically to maintain corruption than it is to reduce CO_2 emission-related restrictions (Z. Wang et al., 2018a)). Environmental policy and energy efficiency are closely related, with governance quality playing a major role in both (Apergis & Garćıa, 2019).

The countries chosen for this study have a wide range of high and low-emitting economies. Each has its own socio-economic background, developmental path, and sustainable development philosophy. here, we give you a broad picture of these countries and how their economies have grown during the previous three decades.

An amazing economic revolution has taken place in the world's most populous nation, China, since the late 20th century. China accelerated its industrialization, urbanization, and export-led economy after implementing market-oriented reforms in the late 1970s. China became a world powerhouse in manufacturing and a trade powerhouse during this era of fast economic expansion, marked by double-digit GDP growth rates (Aff. & 2023, n.d.; ÖZERDEN, 2023; Wu & Yao, 2010). China has also made great strides in embracing RE sources, with significant investments in solar, wind, and hydroelectric power in the past few years. Nonetheless, China also has to deal with serious issues including resource depletion, wealth disparity, and air pollution (Q. Hassan et al., 2024a; Rong et al., 2024).

Since the early 1990s, there has been a notable shift in the socio-economic landscape and GDP growth in India, the largest democracy in the world and one of the fastest-growing economies. India experienced fast GDP growth after economic liberalization changes, fuelled by its expanding services sector, strong domestic demand, and growing integration into the global economy(Agarwal & Whalley, 2015; K. Bhattarai, n.d.; Swain, 2007). Nonetheless, India continues to face enduring issues like deforestation, inadequate infrastructure, and poverty. With the goal of reducing its dependency on FF and raising the proportion of RE in its energy mix, India has been working to encourage the use of RE in recent years (Charles Rajesh Kumar & Majid, 2020; Phour, 2024 n.d).

In the recent thirty years, Brazil's economy, with the largest GDP in Latin America, has known both expansive and downturn periods. Brazil has been identified as a country rich in natural resources, mainly energy, minerals, and agriculture, among others. The beginning of the 21st century saw global commodity prices and internal demand ride the wave of the nation’s economic progress. Nonetheless, Brazil’s economy also had to accept factors like political agitation, budget deficit, and inflation. It may be argued that Brazil has implemented steps to take care of environmental problems for instance, deforestation of the Amazon rainforest, and in recent times diversified its energy mix (Nassif et al., 2020; Saleem et al., 2024).

In 1991, when the Soviet Union collapsed, Russia, which is the biggest country and a massive energy producer globally, suffered an economic crisis. Despite market liberalization and privatization, as well as other economic reforms, Russia experienced social unrest, hyperinflation, and economic contraction during the 1990s as it moved toward a market economy (“Russia’s Uncertain Economic Future,” 2015; Rutland, 2018). Russia went through an economic resurgence early in the new millennium, propelled by high oil prices and export earnings. But Russia's economy still depends a lot on energy exports, so it's susceptible to changes in the price of gas and oil across the world. Russia has been working to diversify and innovate in the energy sector as well as modernize it in recent years (Austvik, 2016; Avdasheva, 2023).

The United States, being the world's largest economy and a prominent global economic force, has seen phases of economic growth and decline throughout the last thirty years. The United States is renowned for its vibrant and varied economy, which has witnessed strong growth in its GDP, propelled by innovation, entrepreneurship, and technological progress (Economy & 2020, n.d.; Xin et al., 2022). The adoption of RE in the United States is a prominent trend, with significant investments made in solar, wind, and other clean energy technologies(Idoko et al., 2024; Uwaoma et al., 2023). Nevertheless, the United States encounters obstacles such as disparities in economic distribution, deficiencies in infrastructure, and deterioration of the environment, encompassing CO_2 emission and climate change (Adebayo & Özkan, 2024)

Over the past thirty years, Sweden, a Nordic nation renowned for its social safety system and high standard of living, has steadily grown economically and socio-economically. Sweden is an advanced country that has placed great importance on innovation, education, and the environment. Therefore, it has become a global leader in the field of transition to renewable energy, environmental conservation, social equality(Ramasar et al., 2022; Sarasini, 2009). Sweden has pledged to apply very ambitious policies aiming to moderate CO_2 emissions and reach carbon neutrality. The country has channeled notable resources into the development of RE sources, including wind, solar, and biofuels (Bergek & Mignon, 2017).

Known for the presence of oil and gas Norway is a Scandinavian country that has considerably progressed both socially and economically as its economy has prospered during the past three decades (Q. Hassan et al., 2024b). Norway is oil and gas rich, and despite this, Norway also put their income from oil and gas in a fund meant for the long term and for the diversification of their economy (Gasparini, 2023). Also, Norway has been the pioneer in RE use especially in the production of hydropower and he also works in environmental conservation and sustainable development (May et al., 2012).

Switzerland, a landlocked country in the Central Europe region, is globally known for its finance, banking, and manufacturing sectors. The economy of the country is made up of advanced and diversified industries. In the realm of the last thirty years, innovation, entrepreneurship, and human capital became the decisive factors for Switzerland’s economic growth and social stability. Switzerland has had the lead in renewables endeavors with the investment in wind, solar, and hydro as well as decreasing its carbon footprint and advancing sustainable development(Reskiyah, 2023; Schneider & Vallet, 2019) .

The Pacific islands, which host New Zealand as a country, are noteworthy for the high quality of their exports, tourism, and agriculture, and the latter sits at a modest but robust level. In the last three decades, New Zealand's natural resource endowment and export-oriented sectors were the main drivers for the country's moderate growth and the social progress achieved. Besides pushing towards environmental sustainability and conservation, New Zealand has also put forward initiatives aimed at achieving the goal of using RE sources such as geothermal power and wind.

Costa Rica, a country in Central America that is famous for its rich biodiversity and which has conducted ecotourism successfully, has been successful in achieving economic growth and socio-economic progress in the past thirty years (O. Banerjee et al., 2024; Gunter et al., 2017). Costa Rica has invested in domains of education, healthcare, and environment that have led to improved human development indices and a good reputation for sustainability (Nguyễn & Phan, 2023). RE has the potential to increase as Costa Rica leads the way with 99% of its electricity generated from hydropower, wind, and geothermal energy (Peraza Quirós et al., 2023).

1.0. Statement of the Problem

Despite the great world initiatives towards addressing climate change and promoting sustainable growth, the bigger obstacle is still the coexistence of the two factors. This issue is especially highlighted in poor nations with low CO_2 emissions and in rising economies that emit high CO_2 levels. Concerning policy achievements and the creation of sustainable development objectives, we should have a clue about the intricate bonds that link economic indicators, energy utilization patterns, innovation, and CO_2 emissions in those economic contexts and others. The study problem statement centers on investigating the ways in which different economic parameters, like GDP per capita, the availability of RE, the use of FF, and the quantity of PTS, impact CO_2 emissions. Critical issues emerge like what are the factors behind emissions, how different policies work in reducing emissions, and whether it is where economies can be sustainable with environmental preservation and economic growth. The equality question is also a topic for discussion in the case of comparing the emission amounts of growing and developing economies because it is the subject of the contribution responsibility and collaboration on the World's environmental problems. It is mainly the emerging economies that are the culprits of CO_2 emission globally due to their fast industrialization and energy-intensive development pathways, whereas the developing economies with lower emissions also have challenges in attaining sustainable growth goals without impacting the social welfare and the standard of living.

Therefore, the statement of the problem for this research encompasses the following key aspects:

1. Understanding the drivers and dynamics of CO_2 emissions in economies with high emissions and with low emissions.

2. Examining the effect of economic indicators including GDP, energy consumption pattern, innovation, and policy interventions on CO_2 emission in both high and low emissions economies.

3. Investigating various economic growth and environmental sustainability trade-offs and synergies that arise in the context of existing and emerging economies.

4. Dealing with equitable representation, responsibility and collaboration among the global players in the efforts to decrease CO_2 emissions and to promote sustainable development.

Through the analysis of these obstacles and opportunities, this study mainly aims to widen our understanding of the challenges and consequences that economic development as well as environmental conservation pose to any economic setting. It is designed to offer strategic guidance for policy making, investment in RE sectors and cooperation among the concerned countries to fight climate change and push the sustainable development.

1.1. Purpose of the Study/Research Objectives

This study should refocus on conducting a deep comparative study of GDP per capita, the increase of RE, decline of FF energy consumption, patenting, and CO_2 emission. Moreover, it is aimed to expose patterns formed by the CO_2 releases of all high-growth countries as opposed to the less developed nations, between 1990 and 2020. Evaluating various causes imported by CO_2 emissions in high and low-emitting countries is the principal objective hereof. The study measures the impact that GDP per capita, the rate at which RE was adopted, the amount of fossil fuel combustion, and the number of PTS have on the emission of gases for the reference time.

This paper's main objective is to analyze and assess the efficacy of these laws and policies in lowering CO_2 emissions and advancing the SDGs' objectives. It is worthy of careful examination as to how well the consequences of those policies, comprised of encouragement of RE and carbon taxing, which has to do with two things: namely, reduction of CO_2 emissions and strengthening of economic performance, can be executed. Additionally, the research wants to address the essential trade-offs and complements issues in relation to economic growth and natural sustainability existing in different economies. The status of the spillover of the rising economies into CO_2 emissions as part of economic advancement and responsible ecological management is another one of their roles. Another matter is how less emissions of the developing economies are possible and new pathways together with the upturn of development are provided.

Moreover, this work addresses explicitly the problems of unfairness, common accountability, and increased cooperation within the international programs that want to reduce CO_2 emissions and encourage the effective accomplishment of sustainable development goals. The which talks about not only the emergence and development of countries but also their role in forums like the climate negotiations and tech transfer agreements in the sense of global concurrence in the SDGs of the United Nations and the Paris Agreement, is included in this review. In the final analysis, the research attempts to present useful findings and guidance to policymakers, stakeholders, and executants which they will use to formulate and implement effective ways of substantially reducing the rate of CO_2 emissions as well as in the achievement of SDGs. Doing an in-depth exploration of the data and an interpretative analysis of it will be the main aim of the research, so the decision-making procedure could be developed on the basis of evidence and collaborative discussions would be encouraged for climate change mitigation and sustainable development at varying levels. However, the investigation in addition also addresses some challenging questions about equality, equal responsibility, and cooperation in international mechanisms for the emergence of sustainable development CO_2 emissions production control who is guiding the development. It requires a thorough examination of the subordinate and developing economies' participation in the global groupings, such as climate negotiations and technologies transfer agreements, guided by global accords such as the SDGs of the UN and the Paris Agreement. Overall, the outlined research objectives provide a solid foundation for this study, providing a structured framework for investigating the complex connections between economic growth, energy transition, innovation, and environmental sustainability in high and low CO_2 economies. With a focus on thorough analysis and interpretation of real-world data, the research aims to provide valuable insights that can inform policy decisions and contribute to the global pursuit of SDGs.

1.2. Research Questions/Hypotheses

1. Research Questions:

- What are the primary drivers of CO_2 emissions in economies with high and low CO_2 emissions?
- How do key economic indicators such as GDP per capita, RE adoption, FF energy consumption, and PTS correlate with CO_2 emissions in these diverse economic contexts?
- What is the impact of policy interventions and regulatory measures on CO_2 emissions reduction and economic performance in high and low-emission economies?
- How do these economies contribute to global efforts to mitigate CO_2 emissions and promote sustainable development, and what roles do equity, responsibility, and collaboration play in these efforts?

Hypotheses:

- H1: Higher levels of GDP per capita will be negatively correlated with higher CO_2 emissions in both high and low-emitting economies.

- H2: Greater adoption of RE sources will be negatively correlated with CO_2 emissions in both high and low-emitting economies.

- H3: Increased fossil fuel energy consumption will be positively correlated with higher CO_2 emissions in both high and low-emitting economies.

- H4: Higher levels of PTS will be positively associated with technological innovation and may lead to reduced CO_2 emissions in both high and low-emitting economies.

- H5: Policy interventions such as RE incentives, carbon pricing mechanisms, and technological innovation policies will have a significant impact on reducing CO_2 emissions and promoting sustainable development goals in both high and low emitting economies.

- H6: Economies with high CO_2 emissions may face greater challenges in achieving economic development goals while reducing their environmental footprint compared to economies with low CO_2 emissions.

- H7: Collaborative efforts and international cooperation among high and low-emitting economies will be essential for effectively addressing global climate change challenges and achieving the objectives of the Paris Agreement and the United Nations SDGs.

Using these research questions and hypotheses as a framework, the study explores the intricate relationship between economic indicators, patterns of energy use, innovation, and CO_2 emissions in both high and low-emissions economies. They offer a structure for analyzing and interpreting data, making it easier to examine important trends, inequalities, and policy implications in the study's conclusions.

1.3. Significance of the Study

The study has significance through its ability to offer practical suggestions and guidelines to academic researchers as well as practical policymakers who can implement the strategies of environmental sustainability. Thus, this research is expected to identify a narrow set of critical problems and deliver the practical effect of the work with a comparative study of the interaction between the economic determinants, energy consumption styles, and innovation, on CO_2 emission in high and low-emitting countries.

The findings of this research shall provide policymakers with an array of evidences that can be the basis for their evaluations on the effectiveness of myriads of interventions and regulatory policies directed towards the elimination of CO_2 and in this regard, their contribution toward the achievement of the sustainable development goals. This method has opportunities to help the work of politicians in drafting and implementing these targeted policies to have a huge influence on the globe when implementing the mitigation of climate change and the achievement of environmental sustainability. This research can be a source of knowledge that may support investors and businesses on their way to making wise decisions regarding investments related to sustainability. Trans-national understanding of the ways and means of CO_2 emissions in growing and less-advanced markets aid in the recognition of the leading industry likely to reach new levels of innovation while simultaneously tackling the negative environmental outcomes.

Undertaking this research replenishes the trending scholar's narrative on the complex network among economic development, energy consumption, innovation, and CO_2 emission. The present approach enlarges the existing theories and empiric studies, that brings up the new thoughts and opinions about the narrow underlying factors and wide scope of environmental developments which is clearly visible in all economic settings. The research outcomes point us to the possibility of improved dialogue and collaboration among the states, agencies, and people participating in global efforts towards green development and carbon emission reduction. The finding of the prevalent barriers, as well as the illustration of the most effective models, could drive more constructive collaboration and coordination in the fight against climate change that can go beyond one nation and create remarkable regional and worldwide impact.

This study possesses the capacity to enable communities and individuals to actively engage in efforts aimed at mitigating climate change and advancing environmental sustainability. This research has the potential to stimulate grassroots initiatives and community-led endeavors aimed at fostering positive change by increasing awareness regarding the factors that contribute to CO_2 emissions and emphasizing the significance of sustainable development. In general, the importance of this work goes beyond scholarly investigation and encompasses practical implications for policy, practice, and collaborative efforts in tackling a critical contemporary issue: climate change.

1.4. Limitations and Scope of the Study

Despite its comprehensive scope and significant contributions, the study on the relationship between GDP per capita, RE adoption, FF energy consumption, PTS, and CO_2 emissions in high and low-emitting economies spanning from 1990 to 2020 is subject to several limitations:

1. Data Availability and Reliability: There are a number of restrictions connected to the study as the data sources may not be available to a certain degree level or they could be unreliable. For example, volumes of variables such as PTS could be insufficient or inaccurate. While the data collection process may go through different systems in different nations and times, having such differences could particularly weaken the analysis's reliability due to the emergence of discrepancies and inconsistencies. Furthermore, low quality or lack of data in national statistics can undermine the reliability of the research results or they may prove inaccurate requiring researchers to exercise a cautious approach and adopt appropriate methods to ensure the validity of the findings.

2. Cross-Country Comparability: Also, one limitation comes into play as it is difficult to ensure cross-country comparability given that we are comparing distinct socio-economic situations of the chosen countries with different developmental paths. Changes in institutional frameworks, data processing techniques, and reporting practices among nations cause disparities and introduce problems with the measurements that lead to difficulties in interpretation and bias when compared to other countries. Consequently, divergent focuses on policy factors, cultural values, and historical traditions can cause a variation in the relationship pattern of the key variables. This necessitates the need for reconsideration and interpretation of the findings in the context of different nations.

3. Temporal Dynamics and Causal Inference: First, the study spans over a long period, thus enabling the researcher to trace and establish relationships

between variables; the separate parts however remain hard to connect into a whole. While statisticians' tools like regression analysis would show of existence of correlations, we may not definitely infer the causality before the rigorous testing and scrutiny against confounders. Furthermore, the fact that socioeconomic form and ecosystems are not static but dynamic systems poses matters of additional complexity e. g. time lags and nonlinear relations which may cause unnoticeable deviations from a causal chain.

4. Heterogeneity and Generalizability: The sectoral plan of this research sample focuses on high and low-emitting economies comes across various regions, income levels, and stages of development which may create some limitations to generalize findings for other situations. In some cases, indeed, measures have been taken so as to count the countries that are from different continents and economic entities on the board, but then the consequences that arise from cultural differences, such as formal or informal policy environments, and market dynamics might affect the extent of findings that can be generalized. Then, it is necessary to be careful in terms of hypotheses and policy recommendations formulating if they are not supplemented by other kinds of studies.

5. Model Complexity and Interpretation: One of the possible complications in the process of analytical models employed in a study, such as econometric models or systems dynamics models, can be the difficulty in the process of interpreting the information and communicating it. Advanced model construction might assume specific knowledge of the field and mock complexity, which could be an impediment for wider public use and replication purposes. Moreover, the model output interpretation along with the assumption of statistical significance tests requires thoughtful consideration of the basis, model mechanism, and robust analysis of the study including model sensitivity clarification.

6. Dynamic Nature of Energy and Innovation Systems: Energy systems and innovation ecosystems as including among others are marked by continuous technological breakthroughs, rapid policy changes and efforts as well as market fluctuations. The evolutionary arc produced by the static analysis that

looked at the same period, 30 years, may not reveal all the dynamics that are embedded within the systems, emergent trends, disruptions, and non-linear dynamics. Consequently, the results of the investigation could be even though there is an outdated or incomplete because of the fact that circumstances and the advancement change over time. Thus, continued monitoring and updating are a must.

1.5. Scope and Limitations

The goal of this study is to conduct a transparent and detailed comparison of the intricate relationship that key economic indicators, mean of energy consumption trends and innovations have with CO_2 emission, involving economies with high and low emissions that prevailed from 1990 to 2020. The study will only look at the countries picked very carefully which have a wider representation of the different economic group classifications. In more detail, there are main emerging countries which produce enormously CO_2 emissions like China, the US, India, Russia and Brazil. On the other hand, some developing countries have small carbon dioxide levels like Sweden, Norway, New Zealand, Costa Rica, and Switzerland.

The quantitative method with high statistical power and econometric modeling will be utilized to do the analysis of the datasets acquired from copyright organizations as well as public databases and research studies. The research will achieve this goal through a deep inspection of the change in CO_2 emission trajectories under different economic conditions, which will supply precious knowledge on the necessary driving forces and dynamics of environmental change amidst economic development.

Although the study trying to keep high level of rigorous validity, there exist some limitations for the study design and execution. Initially, the chosen countries, though being those which are at the level representative of the classifications, may not fully reflect the heterogeneity that characterized those classes. Hence it is prudent to be cautious in generalizing the findings beyond the chosen sample's limits. As a result, inaccurate or incomplete data from different countries and varied periods of time can cause a lot of ambiguity and variation, but that would be reduced through careful sensitivity checks and validation processes.

Similarly, one must also acknowledge the limitations that are usually presented by the nature of the quantitative analysis, implying that it may not be able to account for all the intricate and highly compelling issues that affect the link between economic development and CO_2 emissions. The trial will be done by attempting to manage confounding variables and explaining interactions as much as possible and still, the cause of this result may be limited by the observational data nature.

Last, but not least, this research endeavors to offer empirical evidence-supported solutions to policymakers and practitioners, whereas it is worth pointing out the contextual specificity of the results. The policy recommendations which are based on the findings should be used in a context-specific manner that takes into account the social, economic and environmental environments of each country and further testing may be necessary for implementation.

1.6. Contributions to the Study

This study is there to fill in the literature gap that exists in the current body of knowledge on this relationship through concrete economic indicators, and the consumption of fossil fuel in these economies study relies on a thorough database covering more than three decades from 1990 to 2020, to unravel the CO_2 emissions' mechanics, taking into consideration the intersection between economic progress, energy use, and ecological balance. This empirical data expands our knowledge of the reasons and characteristics of CO_2 emission which aids in improving our understanding of the scope of challenges and possibilities of joint efforts to mitigate the consequences of climate change in various economic situations.

For this study, the comparison also tends to make the picture clear between fast-developing and developed economies in terms of CO_2 emissions trajectories. Through the scrutiny of these discrepancies, the research not only expand our awareness of CO_2 emissions patterns but also serves insights on the principles that affect these patterns across various economic scenarios. The approach compares the policies and practices of countries, which enables the stakeholders to identify effective strategies for reducing CO_2 emissions that will promote green economic development, growth, and innovation.

Besides that, this research discloses the very vast and profound impacts on policy-making formulation as well as decision-making in climate change mitigation and sustainable development areas. Policy interventions and regulatory measures, that were identified by the research, add practicality to governors' efforts to tackle both economic development and environmental protection simultaneously. These policy recommendations highlight the overall picture, which requires non-fragmented approaches to sustainability that address the interrelations of socioeconomic and ecological concerns.

Methodologically, this study contributes to the field by employing advanced quantitative techniques, including statistical analysis and econometric modeling, to dissect the intricate web of connections between economic indicators and CO_2 emissions. The findings are more relevant for practitioners and policymakers involved in climate change and sustainable development efforts because of the research's rigorous methodology, which increases their reliability and validity.

Furthermore, by suggesting avenues for future research and highlighting areas where further investigation is warranted, this study lays the groundwork for advancing knowledge and informing evidence-based policymaking efforts in the pursuit of a more sustainable and equitable future. By addressing these dimensions, the research adds valuable insights to the academic literature and informs efforts to tackle the urgent challenges of climate change and promote sustainable development.

The following sections make up the paper's organization. The part titled "Literature review" provides a detailed analysis of the research factors. The section on "Research methods" includes explanations of the study variables as well as information on the research methodologies that were employed. The study's conclusions are given and a discussion of them is included in the section under "Results and Discussion." The final analysis and policy implications are contained in the "Conclusion" section.

CHAPTER 2

Literature Review

2. Review of Related Studies

The creation of the sustainable development agenda and the necessity to fight climate change have become a top priority of the whole world. Being at the foundation of this mission is the recognition and study of the complicated interconnections between energy and growth, innovation, and the environment. This literature review is aimed at revealing the relationships between GDP per capita, current RE adoption, NR consumption, PTS, government effectiveness, and CO_2 emissions. The research is particularly targeted at high CO_2 emissions and low CO_2 emissions economies. The general idea of this comprehensive review is to put together the commonest insights and contributions of all earlier studies and explain how can we get in the depth of the mentioned relationship.

The topic of economic expansion and how it relates to CO_2 emissions as well as the issues with energy use., RE adoption, and innovation has gained substantial attention in the academic community because this issue is important for long-term environmental sustainability and the fight against global warming. A complicated relationship exists between the rise of GDP and CO_2 emissions. that scholars have tried to unravel, with the aim of helping to understand the underlying mechanisms, identify key factors, and develop viable strategies for reducing CO_2 emissions and fostering economic growth at the same time.

Significantly meaningful research has been conducted focusing on the part economic indicators, namely GDP per capita, play in CO_2 emission change trends among high and low-emitting nations. Multiple empirical surveys of the type, for instance, those of. (Androniceanu & Georgescu, 2023; Z. Wang et al., 2016) through a panel data analysis discovered that global CO_2 emissions and GDP per capita are positively related. Research performed by. (Cowan et al., 2014) shows that in countries like China, India, and Brazil During the period of economic expansion, when consumption of energy rises,

CO_2 emissions rise, Additionally, GDP per capita and CO_2 emissions are usually positively correlated. This relationship is usually linked to the energy-demanding character of economic activities in these states, where FF continues to serve as the primary energy source for industrial output, the transportation of goods and services, as well as the production of electricity.

Economic indicators alone are no longer a significant factor in CO_2 emissions patterns. Furthermore, it is crucial to comprehend the trends in energy usage as they strongly influence CO_2 emissions pathways. Empirical studies (K. Li & Lin, 2015; Rehman, Ma, Chishti, et al., 2021) have shown that most of the greenhouse gas emission caused by FF occurs in emerging economies particularly if they have larger urbanization and industrialization rates. Besides that, there are innovations as well as technological advances that play as major players when it comes to CO_2 emissions reduction. Research has illustrated the key role of technical progress in promoting energy efficiency and creating the platform for implementation of low-CO_2 technologies (Lai et al., 2017; Malhotra & Schmidt, 2020) Government's policies and regulations such as those with RE incentives and carbon pricing, in addition, act as a driver for creative and quick change to the low-CO_2

In addition, natural resources, as well as Government effectiveness, are also incorporated as controls to deepen our understanding of how economic growth, patent application, energy consumption, and CO_2 emission link together. The natural endowment of goods like oil, coal, and natural gas is very important for determining which alternative energy sources a nation has and the level of its CO_2 emissions. That is a twofold challenge for countries highly dependent on FF and thus, the transition to RE sources may be particularly hard. Hence, they may see tremendous declines in their trajectories of CO_2 emissions. Government effectiveness, as understood by the quality of governance, institutional capacity, and policy implementation, has as much to do with a country's ability to mitigate CO_2 emissions and drive sustainable development. Execution of strong governance and occurrence of the proper policy frameworks are responsible for the investments in clean energy technologies, control of environmental regulations, and creation of public-private partnerships to deal with climate change issues adequately.

GDP per Capita and CO_2 Emissions

Economic growth expressed by GDP per capita has widely been researched to find a rule on how development and environmental impact affect each other. While the EKC theory for a long time has been the main point of view in these talks, the latest research has been providing complex considerations and alternative perspectives on the link between global warming and economic expansion.(Awan & Azam, 2022; Derege, 2024; Georgescu et al., 2024; Rom & Guillotreau, 2024; X. Zhang et al., 2024). their studies are known for the direct proof that only a monotony can exist in correlation between GDP/capita and CO_2 For instance, numerous authors gave their opinions on the aforementioned matter in their works (Cole et al., 1997; Coondoo & Dinda, 2007; De Bruyn et al., 1998; Shafik, 1994).

The EKC hypothesis postulates that environmental degradation increases with increases in income at first, followed by a reduction of the degradation impacts thus suggesting a negative impact between economic growth and environmental degradation at higher income levels. However, as income levels continue to rise, these impacts eventually improve (Nuţă et al., 2024; Özokcu & Özdemir, 2017; Y. Sun et al., 2024; Yusuf, 2023). Nevertheless, some critics and actual data challenge these findings to the universality of this relationship. For instance, (Stern, 2004a) challenges the EKC hypothesis, arguing that environmental outcomes are contingent upon policy (Burke et al., 2015; Le & Nguyen, 2020) present findings from a global panel dataset, indicating variations in the income-emissions relationship across countries and income levels. Their research highlights the importance of considering contextual factors and heterogeneity in shaping emissions trajectories.

During the discussions focused on achieving a "proper form of growth" that aligns with the goal of decreasing CO_2 emissions, the correlation between GDP growth and CO_2 emissions is examined by some researchers (M. Azam et al., 2016) examines the degradation of the environment, as shown by CO_2 emissions, in several economies with significant CO_2 emissions. The study concludes a positive link between these two variables in China, Japan, and the USA. at the national level. For instance, (Yousefi-Sahzabi et al., 2011) in Iran found a significant correlation between CO_2 emissions and GDP growth. Similarly, (Bouznit & Pablo-Romero, 2016) confirmed these results in their study on the Czech Republic (Lešáková et al., n.d.) According to (Magazzino, 2015), the actual GDP in Israel is a significant factor in determining both energy consumption and CO_2 emissions. A recent study thereby validates earlier findings of the global correlation between GDP growth and CO_2 emission into the atmosphere (Fávero et al., 2022; M. B. Khan et al., 2022). a study by (Bengochea-Morancho et al., 2001) looks into the link between economic growth as measured by GDP per capita and environmental degradation, (specifically CO_2 emissions) in Ten EU countries over the 1998-1995 period. The studies indicate that there exist huge disparities in the intensity and management of emissions, which implies that strategies for ordinary emissions cuts should have to be fashioned according to the financial structure of the single states in the EU. However,(Acaravci & Ozturk, 2010) still note the different situations of nations that constitute the EU. It utilizes the autoregressive distributed lag (ARDL) bounds tests for testing the cointegration approach for nineteen European countries. According to their findings, a causal link exists between both energy and CO_2 emissions and GDP growth in only seven analyzed countries out of nineteen. In terms of methodology, (Bilan et al., n.d.) estimate the coefficients for the variables derived from the equation used in the analysis and assert the existence of a relationship between RE sources, CO_2 emissions, and GDP. Similar to this viewpoint, (Halicioglu, 2009)), vis-à-vis research, supports the fact that GDP growth is positively correlated with energy consumption and higher growth contributes to increased emissions.

The Fully Modified Ordinary Least Square (FMOLS) and Fixed Effects (FE) methodologies are employed by (Dogan & Inglesi-Lotz, 2020) The empirical results showed an inverted U-shaped link between CO_2 emissions and per capita GDP. Dynamic in Ordinary Least Square (DOLS) and System-Generalized Method of Moments (SGMM) were used. conducted by (Zoundi, 2017) to analyze 25 African countries over the period 1980-2012. The result reveals that GDP and rates of CO_2 emissions are positively related, and this relationship is nonlinear.

Regional studies offer detailed information on shaping the intricate link between GDP per capita and CO_2 emissions within particular geographical settings. For example, (P. Liu et al., 2024; Y. Liu et al., 2024; Mehmood Mirza et al., 2022; Sikder et al., 2022; J. Zhang et al., 2023; J. Zhao et al., 2022) based in China, Illustrate the presence of a nonlinear correlation between GDP per capita. However, they take structural reforms and energy efficiency improvements into account as important drivers of emission reduction. On the different side, Works in European countries (Apeaning, 2021; L. Guo et al., 2024; Haberl et al., 2020; Leitão et al., 2022a; Mehmood Mirza et al., 2022), have described how decoupling of emissions from GDP growth is It implies that with the combination of ambitious policies and initiatives on innovation which are the engines of emission reductions and economic growth.

The body of research highlights how governmental decisions and the development of newer technologies have shaped the evolution of the relationship between GDP and CO_2 emissions. In most situations, even the growth of an economy is the main reason for corruption in the emissions but after the policies and investments in clean technologies, decoupling is achieved. Among other things, the success of these activities could be affected by socioeconomic determinations, institutional settings, and policies. Consequently, getting a full picture of country's context is pivotal to designing an adequate strategy for sustainable development and global warming mitigation.

Time series data analysis and econometric models have been used in many studies investigating the similarity of GDP per capita and CO_2 emissions. Contrary to the earlier belief of a direct link between these two variables, recent studies revealed the complex nature of the relationship, whereby factors such as efficiency improvements, sectoral changes, and policy interventions determine the pattern of emissions. For instance, (Jalil & Mahmud, 2009a) found that per capita CO_2 emissions follow an inverted U-shaped relationship for a panel of developing nations, Nevertheless, they noticed substantial differences between countries which some had an emissions intensity reduction starting from where they had low income, and the rest had an increase even when they were in higher income levels. The (Holtz-Eakin & Selden, 1995) study on EKC also states the mixed evidence of EKC in OECD countries, hence it is important to note that sectoral composition, energy intensity, and environmental policy stringency can greatly determine emissions pathways.

Future studies should be based on the theme of GDP per capita and CO_2 emissions and science contexts that keep on changing and emerging horizons. An interdisciplinary approach with economics, environmental science, and policy studies can add on to our knowledge of the mechanisms that cause the emissions trends by studying this subject deeply. Research on climate change and its complex consequences will supply the data necessary for policy decisions that should be evidence-based, and contribute to global initiative towards climate resilience and sustainable development.

Research on developing economies offers exclusive insight into the context of GDP per capita with the changing framework of dynamics that are emerging in the field of industry and social development. On the contrary, (Luzzati & Orsini, 2009) concentrate on the Sub-Saharan African countries and conclude that the CO_2 emissions are positively correlated with GDP per capita which may be an argument that economic growth also causes environmental degradation in these regions. Their results contradict the scale-reversal hypothesis, which postulates a constant EKC and demands policies targeting emissions growth without dismissing economic growth.

Sector studies show infra-detail information on emission patterns in different economic sectors, reflecting the pattern of industrial structure and the future of technology. For example, (L. Sun et al., 2020; Y. Sun et al., 2021) centered on the carbon intensity output in the Chinese manufacturing sector from which they discovered that although generally, CO_2 emissions have gone up as with economic development, carbon intensity has gone down basically as a result of technological innovations and efficiency gains. Their results stress the need for sectoral-based action and avoiding linking economic growth to emissions.

Exploration of the part that international trade and global supply chains play in emitting emissions adds another angle of perspective on the relationship between GDP per capita -and CO_2 emissions (Ibeabuchi et al., 2022; Parker & Bhatti, 2020). For instance, (Davis & Caldeira, 2010a) look into CO_2 emissions in international trade and come to the conclusion that the advanced countries usually transfer carbon-heavy industries to developing economies leading to carbon leakage that causes a wrong assessment of emissions as being done by the top developed countries. Such studies reveal a factor that unites economies worldwide and the imperative to formulate a concerted policy response about the steaming-in of emissions in trade.

Research that shows studies of the relationship between the GDP per capita and CO_2 emission also uncovers the distributional issues that are related to environmental justice and socioeconomic disparities. For instance, (Baloch et al., 2018; Gao & Fan, 2023; B. Yang et al., 2022) study how the income gap overall makes the emissions per capita go higher in these countries. Apart from the research undertaken, equity is of crucial concern when formulating climate policy as the entire population is to be taken on board.

Dynamic modeling techniques and forecasting methods are priceless tools by projecting CO_2 emissions trajectories under varied economic conditions and policy interventions. To exemplify (Braunreiter et al., 2021; Tong et al., 2020) apply integrated assessment models to show the effects of various development perspectives on the emission level globally. The recurrent message of their studies is that the sooner we act and the bolder the measures we take the more successful will be the attempts to limit the emission levels and reach a safe outcome.

Comparative studies aimed to understand how different countries' emissions trends and policy responses are coped with to enable the assessment of the effectiveness of various approaches in emissions reduction and stimulating economic development. To illustrate, (Averchenkova et al., 2016; Stoll &

Mehling, 2021) contrast the climate policies of China, the European Union, and the USA by showing policy differences in their regulatory frameworks, carbon pricing, and RE incentives. Their analysis serves as supporting material in the discussions about policy learning and international collaboration toward global climate change mitigation.

Moreover, adding studies from different areas to the review of the literature enhances its depth offering different views and more profound insights into the intricate interplay between GDP per capita and CO_2 emissions. (Hondroyiannis et al., 2022; Leitão et al., 2022b; Sasmoko et al., 2022; Shahbaz & Patel, 2024; Srivastava et al., 2023) These studies highlight the multifaceted nature of the relationship, emphasizing the importance of considering contextual factors, sectoral dynamics, and policy responses in addressing climate change mitigation and sustainable development.

Renewable Energy Adoption and Fossil Fuel Consumption and CO_2

The general research direction is the substitution of FF by RE sources. This goal is the focus of the attempts to slow down climate change and lower CO_2 emissions. Many researchers have focused on the reasons for adoption, the usability of policy instruments, and the consequences for the security of energy, economics, and the environment.

One of the most common observations by studies is the significance of a favorable policy environment for the development of RE investments. Research by (Sovacool, B.K., 2015. "Global Energy Justice: Principles,... - Google Scholar, n.d.) highlights the non-financial elements that encourage private participation in RE infrastructure, such as renewable portfolio criteria, tax breaks, and feed-in tariffs. The researchers learned that countries with resourceful political structures have a higher percentage of RE sources in their energy mix, consequently lowering their CO_2 emission rate and other health benefits.

Besides that, international studies of different countries and locations are used in order to identify the role of those factors that encourage RE use. On the other hand, (Lin & Li, 2015; Sattich et al., 2021) discuss the policies on RE and their outcomes in China and the EU, emphasizing the influence that strategic, economic, and technological factors have on RE directions. On the other hand, they argue that although China has been very active in the area of renewables, there still exist multiple challenges in coherently incorporating the RE into the grid while addressing institutional impediments.

Even more, the socio-economic impacts of RE adoption explained by researchers portray a possible job creation, GDP growth, and poverty alleviation prospect. Studies like (Carley et al., 2021; Carley & Konisky, 2020) in the United States show that employment growth associated with the installation of RE sources is of higher scale, compared to that of FF per unit of energy produced. These outcomes illustrate how energy development and revitalization can go in hand with a sustainable environment, probably a great motive for a speedy movement towards an environmentally friendly energy system.

Besides, technological innovation is an essential factor in the decline in the costs of renewable energy technologies and the improvement of their performances and dependability. The IPCC reports have been used as a platform to highlight the necessity of bringing to an end our dependency on FF to confine the temperature rise to below two degrees Celsius (2011). The research and development process carried out with the help of both public and private funds, has constantly been leading to significant improvements in solar, wind, biomass, and many other renewable energy technologies (Grubler et al., 2018).

In contrast to this, with the growing use of RE sources, the problem of the worldwide dominance of FF remains to be solved while implementing the strategy of carbon dioxide reduction. The study (Babayomi et al., 2023; Karekezi, S., Kithyoma, W. (2003), Renewable Energy... - Google Scholar, n.d.; J. Wang et al., 2023) looked into the feasibility of RE technologies as options to reduce dependency on FF and CO_2 emissions in Sub-Sahara Africa.

They did research that demonstrated how distributed RE solutions (such as solar PV and mini-grids) can provide clean energy affordable while taking into account environmental impact.

According to the research of (Aldhshan et al., 2021; Falcone, 2023; Gayen et al., 2024; Nayak et al., 2020) the consumption of FF results in environmental degradation, and thus, RE is the only way to achieve sustainable development. they highlight that the policies, capacity building, and the introduction of new technologies could promote the strengthening of RE adoption and the decline of FF and examine the challenges and opportunities of moving to RE sources in the Middle East and North Africa region, provided also the obstacles which limit the financing and set the policy constraints. (Sinha & Shahbaz, 2017) focused on the actual socio-economic impact of implementing RE in India in addition to the fact that it leads to CO_2 emission reduction and benefits the local community through increased job opportunities and income redistribution.

To lower CO_2 emissions, several studies have examined the connection between RE and CO_2 emissions. for instance, (Zhu et al., 2019) simulated the use of variable RE sources, adding solar and wind generators to systems that combine warmth and electricity. (Jebli et al., 2019) studied the relationships between the use of RE, tourism, GDP growth, and CO_2 emissions for countries in South and Central America using panel data spanning from 1995 to 2010. Similarly, the effects of macroeconomic factors, political stability, CO_2 emissions, and RE sources on GDP were examined by (Bilan et al., 2019). In 2020, I. Ullah et al. employed a simultaneous equation approach to analyze the data, (Nathaniel & Iheonu, 2019) examined the association between the decrease in CO_2 emissions in Africa between 1990 and 2014 and the consumption of RE and non-RE. The Augmented Mean Group (AMG) estimate approach was utilized by the researchers. The functions of RE and non-RE were explored by (T. Fatima et al., 2020) in light of the rising CO_2 emissions in the top emitting countries. GDP growth, RE consumption, CO_2 emissions, and value creation in industry and services were investigated by (Ben Jebli et al., 2020) Participating nations in the Belt and Road Initiative (BRI) had their energy consumption, carbon dioxide emissions, and the impact of financial innovation, FDI, and technical innovation predicted both in the short and long term by (A. Khan et al., 2021) For SSA nations, The intertemporal causal link between institutions, CO_2 emissions, RE, and GDP was studied by (Acheampong et al., 2021). According to (Abban et al., 2022), switching to RE sources promotes economic growth positively in oil-producing and natural ecosystems in African countries. (Mehmood, 2021) endeavored to examine the effects of RE on CO_2 emissions, for the G11 economies taking into account variables like GDP, NR, education, and FDI. In their analysis of the relationship between market regulation, environment-related innovation, and RE development and CO_2 emissions in the BRICS countries, (S. Abbas et al., 2022) discovered that the interactions between these variables can be either symmetric (direct) or asymmetric (indirect) that are mediated by market regulations. These relationships suggest that the development of RE sources, the imposition of environmental taxes, and the expansion of green technological innovations should be prioritized by policymakers, to better control CO_2 emission levels and ultimately achieve greater sustainability goals. Furthermore, while energy taxes often have a negative effect on renewable energy, (Dogan et al., 2023) emphasizes the necessity for fiscal instruments to be used wisely. Simultaneously, a fresh study (Hashmi et al. 2022 demonstrates the importance of expansionary monetary policy in advancing the shift to renewable energy. However, as it also helps to reduce CO_2 emissions, energy efficiency should be taken into account in addition to RE sources. (Jahanger et al., 2023) Energy efficiency is crucial because switching to RE sources is a gradual process that requires the use of conventional energy sources since the road to a totally green economy is complex.

To ascertain the long- and short-run coefficient values, (Mehmood, 2022a) used the (CS-ARDL) cross-sectional autoregressive distributed lag approach. Using the Dynamic ARDL simulation technique,(Ali et al., 2023) examined the relationship between carbon emission intensity, urban population, spending on research and development, consumption of renewable and non-renewable energy, and technological innovation in Russia. With RE use having a 0.27% positive impact on carbon emission intensity, they discovered a long-term significant proof. To meet the energy needs of hospital wards and sections that treated COVID-19 patients, (Izadi et al., 2023) included hydrogen energy storage that simulated a hybrid RE system. Utilizing (TVP-SV-VAR) the time-varying parameter-stochastic volatility-vector auto-regression model (Qin et al., 2022) ascertained the temporal trends in US sustainable financing, RE, and CO_2 emissions. The subsequent eleven countries' CO_2 emissions are examined in (Mehmood, 2022b) in relation to the evolution of the banking industry. Another area of study has been the connection between CO_2 emissions and the SDGs. Promoting affordable and sustainable energy is one of the SDG's many attempts to develop practical answers for sustainable growth. According to (L. Wang et al., 2022), the goal understand why individuals choose RE sources and how their consumption of RE is related to income inequality, GDP growth, technical innovation, gross fixed capital formation (GFCF), and CO_2 emissions.(Apergis et al., 2023) It is the first study to look at the relationship between Uzbekistan's 1985–2020 consumption of renewable and non-renewable resources and CO_2 emissions. The study conducted by (H. Khan et al., 2020) used quantile regression techniques to examine the relationship between RE use, carbon emissions, and financial development for 192 nations worldwide. The authors stated that, at the quantile level, every variable is heterogeneous. Financial development has a positive relationship with carbon dioxide, while RE has a negative one.

Many studies have shown that in order for advanced and emerging market economies to achieve their desired rates of economic growth, they must consume more energy, which increases CO_2 emissions. Consequently, there has been a growing interest in researching how natural gas and RE usage affect CO_2 emissions in recent years. For example, between 1980 and 2006, six emerging economies RE consumption variables were examined by (Salim & Rafiq, 2012a) They discovered that in developing nations like China and India, the usage of RE was highly influenced by CO_2 emissions and GDP growth. They also noted a reciprocal relationship between RE and India, China, and Brazil's CO_2 emissions. By taking into account China's CO_2 emissions from 1977 to 2011, (Lin & Moubarak, 2014a) looked at the similar use of RE and GDP growth. The usage of RE and CO_2 emissions did not appear to be causally related. The effects of non-RE consumption and RE on China's GDP growth and CO_2 emissions were studied by (Long et al., 2015)). According to their report, CO_2 emissions have been considerably decreased by the use of RE. In the USA, similar findings were reported by (Jaforullah & King, 2015)), and in the Next 11 countries, by (Paramati, Mo, et al., 2017a) But according to (Menyah & Wolde-Rufael, 2010a), using nuclear energy can assist cut CO_2 emissions, whereas using RE cannot considerably cut CO_2 emissions in the USA between 1960 and 2007. Additionally, the scientists discovered that while there is no direct relationship between the use of RE sources and CO_2 emissions, nuclear energy does cause CO_2 emissions. According to research by (Bloch et al., 2015a) , in China, the use of coal raises CO_2 emissions whereas the use of RE lowers them. Comparably, (Al-Mulali et al., 2016) discovered that throughout the years 1980–2012, Kenya's CO_2 emissions were greatly reduced by RE consumption, but fossil fuel energy use had a positive impact on CO_2 emissions. In 15 EU nations, the effects of RE and non-RE consumption on CO_2 emissions were studied between 1980 and 2012. (Dogan & Seker, 2016) . According to their findings, using RE has significantly reduced CO_2 emissions whereas using non-RE has resulted in an increase in emissions. Additionally, the researchers found evidence of both unidirectional causality from non-RE use to CO_2 emissions and reciprocal connectivity between RE consumption and CO_2 emissions. In a study conducted between 1991 and 2012, (Bhattacharya et al., 2017) looked at the effect of public institutions alongside the use of RE sources on CO_2 emissions and a nation's GDP growth in 85 industrialized and developing nations. The utilization of RE is found to both positively and negatively impact CO_2 emissions increase. They also provided evidence that institutions have an adverse effect on CO_2 emissions but a favorable effect on GDP growth. Most recently, a panel of G20 economies showed that using RE boosts GDP growth and lowers CO_2 emissions (Paramati, Mo, et al., 2017b).

(Apergis & Payne, 2009) the study used a panel VECM model to investigate the causal relationship between GDP, FF energy, and CO_2 emissions in Central American countries between 1971 and 2004. Their experimental findings supported the idea that GDP follows an inverted U-shaped pattern linked to the EKC theory. The long-term use of FF increases CO_2 emissions in a direct positive way. Furthermore, there is a reciprocal causal relationship between the use of FF and CO_2 emissions, as well as between the use of FF and GDP. It is proven that this causal relationship is bidirectional.

(Jalil & Mahmud, 2009) discovered that CO_2 emissions and China's usage of fossil fuels, economic expansion, and international trade have a long-term equilibrium relationship. To bolster their conclusions, they employed time series data. Their study validated the EKC association's accuracy from 1975 to 2005. For GDP growth and carbon emissions, the Granger causality analysis indicated a unidirectional link. The findings also showed that, over time, income and the use of FF are factors that determine CO_2 emissions.

The model ARDL was employed by (Seker et al., 2015) to investigate the effects of economic development, fossil energy use, and international foreign direct investment (IFDI) on CO_2 levels in Turkey between 1974 – 2010. The findings of the investigation confirmed that the EKC theory is accurate. Long-term causal links exist between FF, GDP growth, FDI, and CO_2 emissions. Turkey should prioritize sustainable growth and promote energy efficiency, according to their findings. To further aid in the protection of the environment, FDI ought to be focused on technologically advanced and ecologically conscious enterprises.

The (Sulaiman et al., 2013)) research examined the relationships among FF, GDP growth, CO_2 emissions, and both the short and long-term. Through the analysis of aggregated and disaggregated energy statistics for Malaysia from 1980 to 2009, the researchers tested the EKC hypothesis. The data on aggregated energy did not show any evidence of an inverted U-shaped curve. Nonetheless, an EKC was confirmed by the results of disaggregated energy data, which covers particular energy sources including electricity, gas, coal, and oil.

(Shahbaz et al., 2014) the study used the ARDL bound test approach to analyze the EKC in Tunisia from 1971 to 2010. The EKC theory was confirmed by the computed results. Additionally, the research showed that trade openness, economic development, fossil energy use, and carbon emissions were all in long-term balance. Their analysis made clear how important it is to encourage sustainable economic growth by enacting laws and policies that protect the environment and limit the entry of air pollutants into the environment. Significant policy consequences for nations result from these findings.

The study by (A. Ahmad et al., 2016)) looked at the relationship between CO_2 emissions, economic development, and the use of fossil fuels from 1971 to 2014. At the general and specific energy levels, the calculated results verified the presence of the EKC in India. Additionally, it has been demonstrated that there is a reciprocal relationship between CO_2 emissions and GDP growth and that the use of FF energy lowers carbon dioxide levels. Furthermore, the presence of a "threshold" or "regime shift" combining the EKC with the time series for the Indian economy between 1971 and 2008 were both verified by (Kanjilal & Ghosh, 2013) The empirical results also show that the Indian economy's energy consumption, GDP per capita, and CO_2 emissions are strongly correlated.

(Nasir & Ur Rehman, 2011) the study used the Johansen co-integration method for analyzing the correlation between GDP, CO_2 emissions, FF usage, and foreign trade between 1972 and 2008. The existence of Pakistan's EKC has been confirmed by the experimental results. On top of that, FF energy use and international trade reduce carbon emissions. The impact of "financial development, per capita real income, the square of per capita real income, per capita energy consumption, and trade openness" on per capita CO_2 emissions in the Pakistani economy was examined by Javid and Sharif in their 2016 analysis. The years 1972–2013 were included in the research. The EKC theory was supported by their empirical findings in the short and long terms. They added that the main causes of Pakistan's environmental degradation are the country's economic expansion, its reliance on fossil fuels for energy, and its financial advancement.

In 2011, (Pao & Tsai, 2011) conducted a study that looked at the long-term relationships between economic development, energy consumption from FF, inward FDI, and CO_2 emissions in the BRIC countries. To evaluate the data, the researchers employed Granger causality analysis and co-integration. The results of their investigation showed that inward FDI reduced CO_2 emissions comparatively. Furthermore, in the BRIC countries, the experimental results have confirmed the validity of the EKC theory. Furthermore, the study has shown that CO_2 emissions and FDI are correlated. The BRIC countries, which rely largely on energy, should strategically manage their FDI and direct more resources towards energy supply and efficiency, according to their empirical findings. Without sacrificing their ability to compete, this strategy would aid in lowering air pollution levels.

In order to examine the dynamic relationship between economic development, FF energy, and CO_2 emissions in Pakistan from 1971 to 2009, (Mirza & Kanwal, 2017) used the Johansen test, the Autoregressive distributed lag model, and the vector error correction model. The researcher underlined how FF energy, CO_2, and GDP growth are all interrelated. Similarly, using the Johansen test, ARDL model, and VECM, Jahangir Alam (Jahangir Alam et al., 2012)) examined the dynamic relationship between FF energy, electricity consumption, CO_2 emissions, and economic development in Bangladesh. The results showed a unidirectional causal relationship, suggesting that FF energy has a major short and long-term influence on economic development. In the short run, they also discovered a unidirectional relationship, with FF energy causing CO_2 emissions. On the other hand, over time, they noticed a feedback causal relationship. Moreover, there is a causal association between long- and medium-term economic development and CO_2 emissions.

The study by (Nkengfack et al., 2019) looked at the connection between energy from fossil fuels, economic development, and CO_2 emissions. For the countries of Algeria, Egypt, and South Africa, spanning the years 1971 to 2015, the researchers used the ARDL technique and performed the Toda-Yamamoto test. According to the study, Algeria, Egypt, and South Africa can experience both short- and long-term reductions in carbon dioxide levels through economic expansion and community energy. Each of these three countries' particular fossil fuel and coal consumption contributes significantly to the nation's CO_2 emissions.

The relationship between fossil fuel energy, CO_2 emissions, and economic development was examined in the study done in 2016 by (Saidi & Hammami, 2016) The scientists employed dynamic simultaneous-equation panel data from 58 nations between 1990 - 2012. Correlations between the following regional panels were calculated by the researchers: "North Africa and the SSA region, Europe and North Asia, Latin America and the Caribbean, and the Middle East." For every panel, found that CO_2, FF energy, and economic development were a bidirectional link. Additionally, there exists a one-way relationship wherein the Caribbean and Latin American regions' economic progress is adversely affected by CO_2 emissions. This suggests that GDP growth is adversely affected by air pollution.

Renewable energy consumption, and economic growth

The relationship between the use of renewable energy and rising GDP in developed and developing market economies has been the subject of many studies. Having said that, the conclusions are not clear. For example, between 1985 and 2005, researchers in 20 OECD nations looked at the correlation between RE use and GDP growth (Apergis & Payne, 2010)). Economic growth is positively affected by RE use, according to their findings. They found evidence of a two-way causal relationship between RE consumption and GDP growth to increase the production of renewable energy, they also contend that the government should implement tax credits, portfolio standards for renewable energy, and the development and expansion of a RE system that slows down environmental deterioration. The research was conducted in six Central American countries. (Apergis & Payne, 2011) in eighty countries; (Apergis & Payne, 2012) in twenty OECD countries; (Ohler & Fetters, 2014) in China; (Lin & Moubarak, 2014b) and in Beijing (Bloch et al., 2015b) comparable findings were reported. Still (Menyah & Wolde-Rufael, 2010b) discovered a direct correlation between rising US GDP and domestic energy consumption. From 1980 to 2006, six developing economies saw a considerable increase in RE as a result of economic expansion (Salim & Rafiq, 2012b)). In addition, there was bidirectional causation between RE consumption and GDP growth, they found that in Turkey, Brazil, China, and the Philippines, while in India and Indonesia, it was a one-way street. Similarly, a study conducted in Turkey between 1990 and 2010 indicated that the usage of RE sources had a detrimental effect on GDP growth (Ocal & Aslan, 2013)). Not only that, However, they established a unidirectional relationship between the growth of GDP and the consumption of RE. Finally, there is a school of thought that contends there is no correlation between RE consumption and GDP growth. As an example, (Payne, 2009) used the Toda-Yamamoto causality test to determine that there was no correlation between US GDP growth from 1949 to 2006 and RE consumption. (Menegaki, 2011) recorded identical outcomes in 27 European nations and (Ben Aïssa et al., 2014) in 11 African nations. A limited number of studies have recently shown that RE use contributes to GDP growth. The utilization of RE sources significantly and positively affects GDP growth in 34 OECD nations, (Inglesi-Lotz, 2016)). In a similar vein, (Bhattacharya et al., 2016) found that, from 1991 to 2012, the top 38 countries in the world for RE consumption all had positive effects on GDP growth. From 1990 to 2012, eleven nations' economies benefited from RE use, according to a study (Paramati, Sinha, et al., 2017). Additionally, they were unable to prove a correlation between the two factors. Both the recent study by (Kutan et al., 2018; Paramati et al., 2018) found that the use of RE sources significantly boosts economic production for a panel of G20 nations and for large emerging market economies, respectively. In addition, there is no correlation between RE use and economic output, according to their findings. Using RE slowed South Korea's GDP growth from 1990 to 2012, according to a recent study (Lee & Jung, 2018) They also found that there was a unidirectional causal relationship between GDP growth and RE consumption in their Granger causality test. Consumption of RE sources and economic complexity positively affected GDP growth in the United States from 1965 to 2016, according to a recent analysis (Gozgor, 2018) . Among 27 OECD nations studied from 1990 to 2013, the most recent study (Gozgor et al., 2018) found that economic complexity, the usage of renewable and non-renewable energy sources, and overall economic use all contributed positively to economic growth.

The relationship between rising incomes and energy use has been the subject of several studies. analysing various categories such as coal, oil, natural gas, and electricity. For example, a study conducted by(H. Y. Yang, 2000) examined the link between economic growth and energy consumption in Taiwan from 1954 to 1997. The study analyzed the relationship at both overall and detailed levels, considering coal, oil, natural gas, and electricity. There is evidence of a unidirectional connection With relation to economic growth and the usage of natural gas, as observed by the author. Iran also yielded similar findings, as discovered by (Lotfalipour et al., 2010) Nevertheless, a study conducted by, (Hu & Lin, 2008) examined the relationship between personal energy use and Taiwan's economic expansion from 1982 to 2006. It was found that the use of natural gas and economic growth are correlated in both directions. During a disaggregate analysis in Malaysia, (Saboori et al., n.d.) researchers discovered a unidirectional connection where natural gas consumption influenced short-term economic growth. However, in the long run, they observed a bidirectional connection between the two variables. In a study conducted by, (Bildirici & Bakirtas, 2014) The primary objective was to examine the relationship between GDP growth and energy consumption in the BRICS countries as a whole. The study covered the years 1980-2011. In Brazil, Russia, and Turkey, there is a strong correlation between the use of natural gas and the expansion of their economies.

An analysis of the literature on the relationship between GDP growth, non-RE, and RE finds that most research indicates that non-RE has a negative impact on growth whereas RE has a positive one. (Awodumi & Adewuyi, 2020; Bekun, Emir, et al., 2019; Kahia et al., 2016; Koçak & Şarkgüneşi, 2017; Luqman et al., 2019; Maji et al., 2019; Ntanos et al., 2018; Zaidi et al., 2018) shown that RE contributed positively to GDP growth using the ARDL method. Moreover, non-RE was a destructor of GDP growth, and a constructor of greenhouse gas emissions in some cases. Such research provides grounds to believe that the growth of RE might be a contributing factor to economic development while reduction of the non-RE consumption can result in GDP growth as well as CO_2 emission mitigation.

(Bekun, 2019) looked at the connections between GDP growth in Romania, energy intensity, carbon emissions, and the use of renewable energy sources. Using the NAR-DLM as a tool for data analysis, it was possible to determine that while Emissions of carbon and energy intensity reduce GDP growth but increase the usage of RE.

(Aydoğan & Vardar, 2020) the study examined how the E7 countries' CO_2 emissions were affected by agriculture, economic expansion, and RE. They utilized the EKC model to analysed the data and found that using RE increased GDP growth while decreasing CO_2 emissions. (Mahmood et al., 2019) the study looked at the connections between CO_2 emissions, GDP growth, human capital, and RE. According to the results, switching to RE sources boosts GDP while cutting down on carbon emissions. Using the EKC model, (Zafar et al., 2019) looked into how carbon emissions and trade openness were affected by the use of renewable and non-renewable energy sources. The study found that while RE use is positively correlated with GDP growth, CO_2 emissions are negatively correlated with RE use.

(Ridzuan et al., 2020) looked into how economic growth, RE, and agriculture affected CO_2 emissions. This set of data was analyzed using the EKC model. The result showed that RE use reduces CO_2 emissions and is a factor in GDP growth (Q. Wang & Wang, 2020) looked into how RE affected the GDP growth of OECD nations. The analysis, which made use of the dynamics of the nonlinear panel data, showed that the consumption of RE positively impacts GDP growth. (Q. Abbas et al., 2020) examined the relationship between economic growth, carbon emissions, and investments in traditional energy, RE, and fixed capital creation. Consumption of RE was found to have a negative impact on carbon dioxide output and a positive effect on GDP growth.

(Afroz & Muhibbullah, 2022) examined the correlation between RE and non-RE in Malaysia's GDP growth through the application of a nonlinear ARDL model. The information showed that while the use of RE sources had a negative impact on GDP growth rates, the use of non-RE sources had a positive impact. Secondly, a policy mix that backs the development of renewable sources of power and technology as well is another viable one as it reduces environmental degradation (Suki et al., 2022). Comprising composite indicators,(Fakher et al., 2022) investigated the connection between financial development, environmental quality, economic growth, and RE. According to the research, RE had a negative influence on the use of non-RE but a positive impact on environmental quality and financial development. In order to investigate the connection between environmental sustainability and the use of RE, With the use of cross-national panel data, (Salahodjaev et al., 2022) Their results showed RE consumption often led to a net good impact on the environment, whereas the consumption of non-RE resources in many cases led to harmful effects (Hieu & Mai, 2023) resorted to MMQR modeling in an attempt to determine the impact of renewables on GDP in developing economies & they found that the nexus between RE and economic expansion is unidirectional. Their study results demonstrated that the consumption of renewables had a positive impact on the economic growth of this country, the consumption of non-renewables however has a negative effect. Panel data methods were utilized by (Ping & Shah, 2023) to examine the connection between CO_2 emissions, FDI, RE, financial development, and green financing. After doing the study, they found that CO_2 emissions, FDI, and financial development were all positively impacted by RE. Green financing, however, was discovered to have a detrimental impact. Political stability has a non-symmetrical effect on production-based CO_2 emissions in the UK, utilizing a nonlinear ARDL and frequency causality model, as stated by (Kartal et al., 2023), The work showed that CO_2 emissions followed a trend of increasing political stability, and RE consumption declined as political stability decreased. From the review of the literature, it has been revealed that RE intake enhances economic expansion, financial development, ecological quality, and CO_2 emissions, as opposed to FF energy intake, which results in their reduction Additionally, research has shown that, depending on the situation, variables including political instability, trade openness, and green finance can have different effects on the energy consumption, emissions, and economic conditions. Furthermore, as noted by (Radmehr et al., 2021), the utilization of RE sources not only advances the creation of a diverse power grid but also bolsters energy security, an essential component in times of market volatility.

Patent Application and Innovation and CO_2 Emission

Innovation has been the key catalyst for technological development and is also a major enabling factor for the low-carbon economy. Patents are widely used as indicators of technological advancement and thus serve as a base for the assessment of environmental innovation within individual countries.

The empirical studies analyzing the patenting activity-environment interaction have given even more confusing outcomes, reflecting that the innovation processes are very complex and their impacts can be different. In that light (Ouyang et al., 2020; Popp, 2019) suggests that environmental policies and sanctions may stimulate the advent of research work in clean technologies. Correspondingly (Acemoglu et al., 2012) conclude that companies comply with environmental regulations by investing in cleaner production technologies, which in return leads to a drop in emissions.

On the other hand, there is interconnectivity between the patenting activity and environmental behaviors which is dependent on many factors such as market structure, rules and regulations, and technical developments. For instance, (A. Jaffe et al., n.d.; A. B. Jaffe et al., 2002) claim that environmental policy can spur innovation by means of competition and the nature of technological advances. In monopolistic industries where enterprises possess more market power, regulatory incentives for improvements in technology can have less impact than those in more competitive markets.

Furthermore, sector-specific and technology-domain studies make visible the underlying dynamics of environmental innovation. In regard to RE innovation, researchers focus on the impact of public-private partnerships, research and development (R&D) investments, and intellectual property rights on the rate of technological advancements. A research paper by (Hoppmann, 2016) concentrates on the development of solar photovoltaic technology and finds policy support, technological learning, and knowledge spillovers as the key factors promoting innovation.

Studies on how nature and innovation interact in developing economies give a great understanding of innovation dynamics and sustainable systems of the environment within contexts of fast industrialization and socio-economic change. Thus(Luzzati & Orsini, 2008; J. Wang & Dong, 2019) studied SSA countries and found that GDP per capita and CO_2 emission positively correlated with each other, suggesting that GDP growth could be environmental degradation in these regions. Such studies dismantle the human Environmental Kuznets Curve and call attention to the fact that at present, there exist no tailored policies that would at the same time address emissions growth and further economic development.

Sectoral studies are the bricks that bring out specific emission patterns related to the elements of economic structure as well as the effect that different types of technology have on emission patterns. Such as,(Lin & Chen, 2019; Y. J. Zhang et al., 2014) study the carbon intensity of China's manufacturing industries and observe the emissions have gone up with the economic growth, but the carbon intensity has dropped because of technological improvement and energy efficiency. The implications of their findings are the significance of the policies development for the economic decoupling of emissions for the sector

The entropy method verified the findings of (Johnstone et al., 2010) about the relationship between technical innovation and the enforcement of environmental policies, particularly in the instance of 25 OECD nations and the RE data from 1978 to 2003. Research consortium established that patent applications and the progression of new renewable technologies were directly linked to the policy decisions. Through the Public expenditure on research and development as the Kyoto Protocol that was designed to stimulate patent-related solar and wind power operations, they mentioned some of the key effects behind innovation activities.

(Fei et al., 2014) looked into the connection between economic growth and RE in Norway and New Zealand between 1971 and 2010. The influence on CO_2 emissions, clean energy, and technological breakthroughs were all studied. The authors claim that a long-term equilibrium between the economy and RE led to a progressive rise in CO_2 emissions. Despite the fact that technical advancements typically lead to better energy efficiency, New Zealand isn't planning to use these innovations to produce RE. Researchers in Denmark, Finland, Norway, and Sweden looked at how RE usage, technical progress, CO_2 emissions, and GDP growth were related (Irandoust, 2016). A unidirectional causal association between technical innovation and RE as well as between RE and economic growth was demonstrated by the empirical results across all of the nations included in the study. The authors underlined the importance of technological innovation in the context of RE sources and how it affects economic expansion.(Y. J. Zhang et al., 2017a) used the SGMM technique in a different study to look at the effects of environmental improvements in China between 2000 and 2013. It is clear that putting policies in place to support environmental, knowledge, and resource innovation helps China cut its CO_2 emissions. Comparable outcomes were found (Samargandi, 2017) in his analysis of the Saudi Arabian context. In a study published in 2018. (Mensah et al., 2018)) looked at how innovation affected CO_2 emissions in 28 OECD member nations between 1990 and 2014. The STIRPAT model was employed by the researchers in their investigation. The scientists came to the conclusion that innovation has a critical role in lowering CO_2 emissions. The authors further asserted that CO_2 emissions increase in correlation with GDP per capita, suggesting a positive relationship between the two. Researchers in the Mediterranean region set out to determine how energy use and CO_2 emissions affected GDP growth (Kahouli, 2018). The role of R&D stocks as a moderator from 1990 to 2016 was their primary focus. The empirical results show that there are robust feedback mechanisms linking GDP growth, R&D spending, power, and CO_2 emissions. Additionally, the research found a one-way causal correlation between R&D

and GDP growth and a second one-way causal relationship between R&D and CO_2 emissions.

(Danish, 2019) likewise demonstrated that the ICT reduced the CO_2 emission in the 59 countries along Belt and Road but in the period of 1990 to 2016. Petrovic and (Petrović & Lobanov, 2020) focused on the connection between CO_2 emissions reduction and R&D expenditures in 16 OECD countries throughout 1981-2014. (Shahbaz et al., 2020) report the same results in their study on the effect of technological innovations in China). The authors determined that technological breakthroughs reduce CO_2 emissions. (Nguyen et al., 2020) agree with this perspective. The authors found that, in addition to energy costs, trade openness, and foreign direct investment, spending on technology and innovation has an impact on lowering CO_2 emissions. They based their analysis on 13 selected G-20 countries between 2000 and 2014. Significant statistical associations between ICT, innovation, and CO_2 emissions were found by the authors. The authors found that investing in R&D over the long run has a negative effect on CO_2 emissions. (Q. Wen et al., 2020) showed that a 1% increase in R&D spending results in an average 0.09–0.15% decrease in CO_2 emissions. looked assessed the impact of technology advancements on CO_2 emissions in the construction sector in 30 Chinese regions between 2000 and 2015. The authors emphasized how important technological innovation is to reducing CO_2 emissions in the construction industry.

Though most research in the literature has demonstrated that innovation modifies CO_2 emissions, certain studies have produced contradicting results, including:

According to (Álvarez-Herránz et al., 2017), a panel dataset consisting of 28 OECD nations was used to examine how changes in energy R&D affected emissions of greenhouse gases from 1990 to 2014. Data suggests that energy innovation projects may take more time to come to fruition and achieve their aims. Between 1971 and 2014, researchers in Tunisia examined the impact of energy consumption, commercial activity, and technical innovation on the country's environmental sustainability (Amri et al., 2019). Technical innovation and CO_2 emissions are not causally related, according to a study. It did discover, though, that technological advancement has a one-way impact on energy usage over the long and short terms. Furthermore, because it lessens the impact of energy use on CO_2 emissions, technological advancement also has an indirect relevance. From 1980 to 2016, researchers in the BRICS countries examined the effects of GDP per capita, RE, and innovation on CO_2 emissions (Khattak et al., 2020). There was no reduction in CO_2 emissions by technical innovation in South Africa, China, India, or Russia, as shown in the test findings. Researchers discovered that there was a two-way causal relationship between innovation and GDP per capita, innovation and RE consumption, and CO_2 emissions and GDP per capita.

In contrast, most research studies innovative technology that lessen the effects of climate change, innovation also plays a role in reducing the environmental impact of climate change. (Su & Moaniba, 2017a) examined the causal link in reverse using a different methodology. The impact of climate change on the creation of innovative technologies was examined by the authors through an examination of a dataset spanning 70 nations. The authors conclude that there is a direct relationship between rising CO_2 emissions and rising adoption of climate change-related technologies. Therefore, the author suggested redirecting governmental funding to innovative projects that directly combat climate change.

From 1996 to 2012, (Du et al., 2019) looked at how developments in green technology affected CO_2 emissions in 71 different countries. According to empirical evidence, in nations where the income level falls below a particular threshold, the impact of green technology advancements on lowering CO_2 emissions is minimal. On the other hand, economies with income levels over the cutoff saw significant declines. The researchers also found an inverse U-shaped association between GDP per capita and CO_2 emissions per capita, as well as between the degree of urbanization and the industrial structure.

Using the STIRPAT model, (Koçak & Ulucak, 2019) examined the relationship between R&D investment and CO_2 emissions in OECD countries between 2003 and 2015. The empirical results showed an unexpected result:

there was a significant and positive link between the amount of money spent on R&D and the amount of CO_2 released into the atmosphere. The correlation was ascribed to improvements in energy efficiency and the utilization of FF in research and development endeavors. The researchers also found that funding energy and storage technology R&D contributes to a decrease in CO_2 emissions.

Previous studies show that the possible relationship between innovation and CO_2 emissions has received a lot of attention. Previous research on the connection between innovation and CO_2 emissions has produced contradictory findings using various samples, approaches, and strategies. Since patents safeguard the rights and intellectual property of businesses looking to innovate solutions to environmental issues, most academics favor them as a stand-in for innovation (Albino et al., 2014; Raiser et al., 2017a) (Y. J. Zhang et al., 2017b). According to (Zhou et al., 2016) China's impending emphasis on the advancement of environmentally friendly technologies represents a collective response to the worrisome levels of global emissions. The BRICS economies are revaluating their economic strategies in light of the importance of environmentally friendly products, procedures, and technology as a result of realizing that quick economic advancement comes at the expense of environmental difficulties. Following the conclusion of the most recent BRICS 2017 Summit in Xiamen, China, the participating countries committed to utilizing innovation to improve the economic, social, and environmental conditions of both the BRICS and the Emerging Markets and Developing Countries (EMDs). According to (Yu & Du, 2019), autonomous innovation projects have contributed significantly to China's decrease in CO_2 emissions (Brandaõ Santana et al., 2015). concluded that technological innovation has enabled sustained economic development throughout the BRICS and G7 economies and has aided in the creation of an efficient energy market (Yii & Geetha, 2017) found a causal relationship between technological advancements, growth, power use, energy pricing, and CO_2 emissions in Malaysia from 1971 to 2013. The findings demonstrated that, despite the lack of a long-term correlation, technological innovation has, in the short term, assisted in lowering CO_2 emissions. The magnitude of regional differences in the efficiency of CO_2 emissions among Chinese metallurgical industry businesses was investigated (Lin & Xu, 2018). According to the empirical estimations, the most significant predictor of an improved Meta-frontier Malmquist CO_2 emissions Performance Index (MMCPI) is the advancement of technical innovation. According to the degree of CO_2 emissions relative to GDP and emissions lags for the BRICS economies between 1980 and 2011, (Azevedo et al., 2018) split the nations into two categories according to the heterogeneity of CO_2 emissions. Despite the fact that there is empirical evidence linking GDP growth and CO_2 emissions as the main factors influencing variations in CO_2 emissions, the authors' findings about the impact of economic activity on CO_2 emissions in various nations were not entirely consistent. The authors came to the conclusion that lowering CO_2 emissions will likely depend heavily on advances in innovation and member countries' understanding of energy savings. (Aldieri et al., 2019) corroborated the idea that innovation explains the OECD economies' lower CO_2 emissions. However,(Su & Moaniba, 2017b), contend that it is important to acknowledge the contradictory findings and the empirical data demonstrating the negligible effect of innovation and/or climate-related technology on CO_2 emissions. According to (Raiser et al., 2017b) patents are thought to impede development and pose a barrier to mitigating the effects of climate change.

Natural Resources and CO_2 emissions

Natural resources, encompassing both renewable and non-renewable sources, play a pivotal role in shaping emissions trajectories and environmental outcomes in both high and low-emitting economies. The exploitation of these resources for energy production, industrialization, and economic growth often comes with significant environmental externalities, including CO_2 emissions and ecosystem degradation. Empirical studies of the complicated link between natural resource sufficiency, patterns of energy consumption and greenhouse gas pollution exist in the literature to illustrate these interactions and the diverse pathways through which resource abundance affects environmental performance.

The link between natural resources and emissions also depends on the economic, institutional, and social structures within which they are managed. institutions serve as channels for regulating the detrimental impacts of extractive resources on the environment and creating sustainable development outcomes. Nations having solid governance systems and transparent institutions remain more capable to work with resource revenues, and by regulating the extractive industries and adequately investing in clean energy transitions. In contrary, deterioration in governance framework and institutional dysfunctions can exacerbate the speed of environmental degradation, so social injustice and political drawbacks thereby, and of course, can undermine attempts to address climate change and achieve sustainable goals.

There is much discussion about how to allocate the rents from NR to exports of CO_2 emissions. It has been claimed by some study that life rents from natural resources could reduce carbon emissions (Ulucak et al., 2020a)). Carbon emissions and energy consumption are frequently high as a result of the exploration and exploitation of oil and other mineral resources throughout the African continent. In addition, because industrialization promotes economic growth, there is a greater need for natural resources now. According to (Kwakwa et al., 2020). the extraction and consumption that follows do harm to the environment. Further investigation suggests that the existence of rents from natural resources is linked to an adverse effect on emissions. For example, NR promotes globalization and improves energy efficiency, which lowers carbon emissions by facilitating the expansion of foreign exchange, foreign investments, and international trade (Sinha & Sengupta, 2019). It has been established that management and institutions affect carbon emissions and the rents from natural resources (Amiri et al., 2019). According to Sofien Tiba and colleagues, countries with inadequate institutions or poor regulatory standards typically use inappropriate technology, which increases their ecological footprint (Tiba & Frikha, 2019).

Few studies have looked into whether NR has the ability to affect CO_2 emissions, though. The relationship between CO_2 emissions, natural resources, globalization, financial development, and GDP growth in China from 1980 to 2017 was investigated in the study.(Umar, Ji, Kirikkaleli, Shahbaz, et al., 2020) The ARDL limits test methodology and the Bayer-Hanck coupled cointegration was utilized by the authors. The study proved that NR reduced CO_2 emissions in a positive way. In particular, a 1% increase in NR causes short-term CO_2 emissions to grow by 0.042% and long-term CO_2 emissions to rise by 0.161%. The authors blame the inappropriate use of natural resources for this negative environmental impact.

In the OECD's member countries between 1980 and 1960, (Ulucak et al., 2020b) looked into the relationship between energy use, economic development, natural resources, and environmental sustainability. Their investigation, which makes use of the AMG estimator, indicates that there is a direct correlation between the extraction of NR and the rise in CO_2 emissions. From 1990 to 2016, (A. Khan et al., 2020) computed the impact of NR on the link between energy, economic growth, and environmental degradation for 51 BRI countries using a GMM technique. It was found that in these nations, NR positively impacted tourism growth, energy consumption, and CO_2 emissions. The idea of the "NR curse" is further supported by the fact that natural resources have a detrimental effect on economic growth. As shown by (Bekun, Alola, et al., 2019a) add the NR as an extra variable to the CO_2 emissions equation for a portion of the EU-16. The researchers used the Kao cointegration test to show that, during the course of the 1996–2014 era, CO_2 emissions were linked to NR, GDP growth, RE, and demand. It was also found that a significant portion of long-term CO_2 emissions are caused by non-renewable rent.

(Danish, Baloch, Mahmood, et al., 2019a) analyzed BRICS data from 1990 to 2015 using the AMG panel algorithm. The aim of the study was to examine how the endowment of natural resources affects greenhouse gas emissions. The various impacts of NR on CO_2 levels in the BRICS nations were inferred by the researchers. They found that whereas NR abundance lowers CO_2 emissions in Russia, it contributes to pollution in South Africa. But no discernible impact was seen in China, India, or Brazil. They also discovered a bidirectional association between these countries' NR and CO_2 emissions.

In a study published in, (H. Liu et al., 2022) examined the relationships—both linear and non-linear—between education, natural resources, and CO_2 emissions in Latin American nations between 1990 and 2020. Using cutting-edge second-generation econometric techniques, they carried out a comprehensive empirical analysis. The findings showed that NR has a non-linear effect on environmental quality. Reduced NR levels appear to benefit the ecosystem in the Latin American context. Nevertheless, increased use of NR causes a corresponding growth in CO_2 emissions. Accordingly, the study concluded that in the Latin American region, there is a U-shaped association between CO_2 emissions and NR. On the other hand, using the EKC framework, (W. Azam et al., 2023b)) investigate how government spending, natural resources, and alternative energy sources affect environmental sustainability in France from 1990 to 2018. FMOLS and the generalized linear model (GLM) are the analytical tools used in this work. Natural resources and government spending on ultimate consumption, CO_2 emissions, and alternative and nuclear energy are inversely related according to their long-term findings. Furthermore, the results show that there is a unidirectional Granger causation relationship between NR and CO_2 emissions.

Many studies have been conducted in both developed and developing economies on the association between NRR and carbon emissions (Chien et al., 2022; W. Li, Chien, Waqas Kamran, et al., 2021). A new supplement, published by (Bekun, Alola, et al., 2019b), looks at the developments of the sustainable environment in 16 EU economies between 1996 and 2014. Resource rent, carbon emissions, and other explanatory variables are the main subjects of the study. The model employed for data analysis was the panel-pooled mean group-autoregressive distributed lagged model. An analysis using long-term estimation shows that there is a positive relationship between an NRR and its carbon emissions. An investigation on the nonlinear link between ecological footprint and NRR in the top 15 RE economies was carried out by (A. Ullah et al., 2021a) Panel smooth transition model was used for data collected between 1996 and 2018. When comparing ecological footprints in high- and low-income regimes, the results show a significant and positive association between NRR. Natural resources and fiscal decentralization's effects on carbon emissions in OECD economies between 1990 and 2018 have been empirically studied by the writers (Tufail et al., 2021) That being said, the results of the study show that utilizing NR rent has a good effect on the environment by lowering CO_2 emissions. In order to determine how energy use and the NRR affected South Africa's CO_2 emissions, (Joshua & Bekun, 2020a) conducted an empirical study. The analysis shows that the overall net rate of return in the South African economy and pollution emission have a consistent link (L. Wang et al., 2020) study explores how the NRR affects CO_2 emissions in the G7 nations in conjunction with other macroeconomic variables. The study results show that G7 countries' CO_2 emissions are rising as a result of their higher NRR. A long-term study of the Chinese economy was conducted by (Tu et al., 2021) spanning from 1995 to 2017. China's NRR and carbon emissions appear to be positively correlated, according to the data. A study by. (Y. Huang et al., 2021) looks at how China's carbon emissions from 1995 to 2019 were affected by energy consumption and NRR. It also looks at whether the EKC exists. It is confirmed by the study's findings that NRR has a major impact on the Chinese economy's environmental state. Furthermore, several other research works have investigated the relationship between NRR and environmental issues, including carbon emissions (Canh et al., n.d.; Chien et al., 2021; Joshua & Bekun, 2020b; J. Li et al., 2021; W. Li, Chien, Hsu, et al., 2021; Ulucak et al., 2020c). The researcher has investigated the relationship between NR and ED-like carbon emissions, based on the literature that has been supplied. For this relationship to be studied in the particular regional context of the USA, more research is necessary. The long-term causal link between CO_2 emissions, environmental deterioration, and natural resource rent was investigated by (Bekun, Alola, et al., 2019c) using a literary analysis. Panel data from 1996 to 2114, covering 16 particular EU countries, is the source of empirical evidence used in this study. With the panel pooled mean group-autoregressive distributive lag model (PMG-ARDL), the data were analysed. The impact of energy resources on greenhouse gas emissions is investigated in this work. According to the results, using natural resources increases the amount of CO_2 released into the atmosphere unless proper management or conservation measures are put in place. In a study by (A. Ullah et al., 2021b) the top 15 economies with high RE consumption were examined to see how they related to NRR, CO_2 emissions, carbon emissions, and environmental quality. Sustainability in development was the aim. Data from 1996 to 2018 are used in the study using panel time series. The relationship between the shift and correlation between the low and high regimes is examined using the panel smooth transition model. The research findings suggest that the process of extracting natural resources leads to an increase in atmospheric carbon dioxide, which in turn exacerbates environmental degradation. In an investigation published in (Razzaq, Wang, et al., 2021) looked into the phenomena of resource depletion brought on by the expansion of infrastructure in resource-intensive economies. They stated that one important way to lessen these negative effects is through innovation. Such results are supported by recent research that used samples from the OECD, China, and the BRICS (Razzaq et al., 2020; Razzaq, Sharif, et al., 2021)

The existing empirical research that has looked at the relationship between CO_2 emissions and NR as a measure of environmental deterioration will be compiled and briefly summarised in this section. NR and CO_2 emissions have been found to positively correlate in numerous types of research. The impact of NR on China's CO_2 emissions between 1995 and 2017 was investigated by (Shen et al. 2021) using the ARDL technique. Their studies show that natural resource discovery has a positive correlation with the production of carbon dioxide in oil and gas sectors which means that CO_2 emissions increase with the discovery of new resources. (Ulucak & Bilgili, 2018) used the AMG model from 1980–2016 to examine the influence of NR on CO_2 emissions in OECD countries. The research report shows that extracting the NR from those countries leads to a rise in CO_2 emissions levels. (M. K. Khan et al., 2021) investigated the connection between natural wealth and CO_2 emissions in the BRI countries covering the 1990-2016 period). Through the application of the GMM model, we were able to identify the relation between the GHG emissions and the NR. Using FMOLS methodology (M. Ahmad et al., 2020b) In the provinces of Gansu, Xinjiang, and Shaanxi, there is a positive association between natural resources (NR) and CO_2 emissions, according to the researchers' examination of north-western China from 1995 to 2017. NR and CO_2 emissions, however, are negatively correlated in Ningxia and Qinghai Province. Using the PMG methodology, Bekun et al. (2019) concluded that, from 1996 to 2014, the presence of NR had a detrimental effect on the environmental quality of sixteen EU economies. (Danish, Baloch, Mahmood, et al., 2019b) employed the AMG model to examine data spanning from 1990 to 2015. Their results are consistent with earlier studies, showing that among the BRICS nations, NR increased CO_2 emissions in Brazil, China, and India. Due to its wealth of resources, the NR simultaneously contributes to Russia's efforts to reduce pollution. Utilizing the STIRPAT model, as outlined in 2022 by (X. Li et al., 2022) Their examination of China between 2003 and 2014 led them to the conclusion that China's increased use of NR causes environmental damage. The ARDL model was employed by Joshua and Bekun. (2020) They found that there is a direct correlation between an increase in CO_2 emissions and the increased use of NR in South Africa between 1970 and 2017., (S. T. Hassan et al., 2019) used the ARDL and VECM models to investigate Pakistan from 1971 to 2017 and found that increased use of NR causes a proportional increase in CO_2 emissions. From 1971 to 2013 (Kwakwa et al. 2019) investigated the interdependent relationship between Ghana's CO_2 emissions and NR. This study found a direct correlation—a positive relationship—between CO_2 emissions and NR using the STIRPAT model. (Nathaniel et al., 2021) showed a positive relationship between NR and CO_2 emissions.

Conversely, certain studies have verified the negative association between NR and CO_2 emissions. (Dong et al., n.d.) utilized AMG long-term methodologies to investigate the relationship between gas NR and environmental quality in the BRICS countries from 1985 to 2016. The research findings indicate that within the designated period, there was an improvement in environmental sustainability when there was a greater quantity of renewable gas. This suggests that over a longer time span, there is a negative correlation between CO_2 emissions and renewable-gas net revenue. GMM models were used by (I. Khan et al., 2022) to investigate the impact of

NR on environmental degradation in the United States. This in-depth study of the evidence that the NR abundance normally results in growing environmental sustainability throughout the period of 1971–2016(Badeeb et al., 2020) was established with the help ARDL model, which the authors applied to study the impact of NR on CO_2 emissions in Malaysia from 1970–2016. This investigation examined whether there exists such a thing as a straight correlation between NR used and the degree to which an environment is damaged. Notwithstanding the fact that my study refuted the theory, it showed that the negative relationship between these NR and environmental degradation existed during the study period. Within the power of Slacks-based measure with window (Z. Wang et al., 2020) the study of the impact of NR on CO_2 emissions in China (2003-2016) and supplied a negative condition between the richness of NR and the efficiency of CO_2 emissions. So, it has been decided by the researchers that because the natural resource endowment is high, the lower efficiency of the exhaust emissions is achieved due to it.

(Balsalobre-Lorente et al., 2018) employed the EKC hypothesis the relationship between EU-5 countries and CO_2 emissions per unit of GDP for the years 1985-2016. This study revealed that the presence of NR and the quality of the environment had a negative correlation with each other, meaning that the production of CO_2 emissions in the environment decreased when the abundance of NR was increasing in the five nations of the European Union. Rich NR allow countries to reduce their dependency on imported FF and efficiently control their CO_2 emissions. (Yu et al. 2016), study used a bio-perspective method-energy analysis to look at 30 provinces in China between 2007 and 2015. They showed how, in some Chinese areas, renewable NR significantly lessens the negative consequences of CO_2 emissions and other greenhouse gases. Despite being one of the least developed provinces, Qinghai Province is the best when it comes to resource sustainability. (Majeed et al., 2021) study looked at the relationship between CO_2 emissions and NR in Gulf Cooperation Council (GCC) nations. The study discovered a negative relationship between CO_2 emissions and NR. As a result, they came to the conclusion that a wealth of natural resources causes

CO_2 emissions to be less efficient. (L. Zhang et al., 2021) employed ARDL models to investigate the impact of NR on environmental degradation in Pakistan. This analysis showed that between 1985 and 2018, there was a considerable decrease in CO_2 emissions associated with an increase in NR.

In conclusion, the relationship between NR and CO_2 emissions in these economies is multifaceted, influenced by factors such as resource endowment, governance quality, technological innovation, and policy support. While non-renewable resources pose challenges to emissions reduction efforts and environmental sustainability, RE sources offer promising pathways for decarbonization and inclusive development. By integrating insights from empirical studies on natural resource management, energy transitions, and environmental governance, policymakers can devise more effective strategies for mitigating emissions, promoting RE adoption, and advancing sustainable development agendas on a global scale.

Government Effectiveness

Government effectiveness that acts through the quality of regulations, rule of law, and institutional capacity has the ability to create crucial emission transition pathways and sustainable development outcomes in these economies. Among others, the empirical research has demonstrated the action-determining impact of governance institutions, regulatory policies, and the organizational unit in bridging the economic activities and the environmental effect to attain the emission levels and ultimately promote sustainable development with the important of good governance.

According to the research of (Kaufmann et al. 2005; Knill et al. 2012), they have their intention to environmentally affect emissions and can do so only when such regulations are effective and determine well the policies that are effective. Agreements between countries erecting high regulatory barriers, clarity of decision-making process, and strict compliance mechanisms permit better repelling environmental issues, limiting emissions, and appreciating investment in environmentally friendly technologies. On the other hand, weak governance structures, the inefficiency in bureaucratic institutions, and corruption can only make it to undermine environmental regulations, which will result in more emissions and hinder the progress toward sustainability goals (Fredriksson and Neumayer, 2016; Damania et al., 2004).

How government effectiveness plays a significant role in the move towards low-carbon energy and promotion of the adoption of RE technologies Brouns et al. (2018) and Koirala et al. (2020 have identified three key areas of the policy to guarantee a high level of private investments in RE: stability of the policy, incentives for investment and partnership with the private sector. In countries where RE targets are clear, special feed-in tariff exists and permission processes are smooth, it is expected that rate of growth in RE capacity and emission reductions are fast. Another side to the puzzle is regulatory uncertainty, policy inconsistency, and administrative obstructions which are the main inhibitors for investors, holders of innovation, and transfer to clean energy sources (Schreuer et al., 2021; Rai et al., 2010).

In addition, as the effectiveness of the government directs the investment priorities and releases the resources, especially in the technology innovation system which speed and scale of the emissions reduction somehow depend on it. The contributions of government landings on policies, public-privation associations, and research finances of clean technologies and emissions reduction have been stressed in the works by Lee and Zhang (2015) and Rosales-Asensio et al. (2019) Countries that have innovation policies that work, technology transfer and the networks that are supportive of their collaborations are better placed in this digital age to make the most of the available energy options of RE, energy efficiency and emissions abatement. Besides this, insufficient government backing, disjointed innovation networks, and poor coordination would all hamper technology diffusion, retard the achievement of the agreed emissions reduction targets, and slow down the switch to sustainable energy systems (Lee et al., 2016; Neuhoff et al., 2019).

Some descriptions have been employed by several research works to depict dimensions of the impact of governance (or institutions) on CO_2 emissions, and they have discovered significant correlations (Halkos & Tzeremes, 2013;

Y. J. Zhang et al., 2016a) employ non-parametric estimators to investigations the assess relating governance and CO_2 emissions. (Halkos et al., 2015) investigate how using a nonparametric approach for regional quality can affect environmental performance in France, Germany, and the UK. These variables are discovered to have a non-linear connection; therefore, good regional quality does not always translate into increased environmental efficiency. Additionally, some studies have examined the effects of various governance indicators on CO_2 emissions. For example, research has established a significant negative non-linear association between CO_2 emissions and corruption control. The control of environmental policy is primarily influenced by political stability and corruption (Fredriksson & Svensson, 2003; Tarverdi, 2018). When institutional elements and the rule of law are included as control variables, the EKC hypothesis is supported (M. Bhattarai & Hammig, 2004).). Some also examine the relationship between the political system, labor union power, and economic and environmental factors. Results indicate that the power of green parties and regulatory frameworks had a favourable effect on environmental quality (Bernauer & Koubi, 2009a; L. Yang et al., 2018)). Additionally, (Dutt, 2009) studies the relationship between governance and institution and income-environment. According to the study's findings, institutional quality and the sustainability of NR are related (Abdala, 2008; Tang et al., 2018). (Danish, Zhang, et al., 2019) examine the impact of governance on environmental pollution in the BRICS nations. The study's findings demonstrated that in the BRICS nations, governance lowers mitigation of climate change.

Improving environmental governance is essential for maintaining environmental quality and guaranteeing sustainable resource use (Samimi et al., n.d.)). A single facet of governance is targeted by several indicators that are included in governance. According to (H. M. Hosseini & Kaneko, 2013b), institutional quality has a major impact on a country's environmental quality as seen from global and regional models. Although the effects of different governance components on the environment vary, institutions' quality has a significant impact on reducing CO_2 emissions. Institutional quality affects CO_2 emissions both directly and indirectly (Abid, 2016b) The effectiveness of green parties and regulatory frameworks has a significant positive impact on air quality (Bernauer & Koubi, 2009b)). Environmental quality is positively correlated with social and democratic elements; democratic governments improve environmental quality by enacting effective environmental regulations. (Almeida & García-Sánchez, 2017). suggest that this could be a result of people's and organizations' increased knowledge of ecological issues (Tamazian & Bhaskara Rao, 2010) have further confirmed the importance of institutional quality on the environment. Moreover, (Lameira et al., 2016). state that efficient environmental governance contributes to the sustainable use of resources. Environmental quality is impacted by corruption both directly and indirectly. It impedes the efficient implementation of environmental laws, directly impairs the functioning of institutions, and encourages rent-seeking activity. On the other hand, it has been discovered that measures to combat corruption led to reduced emissions. (Z. Wang et al., 2018b)), In addition to directly lowering CO_2 emissions, corruption control also has a moderating effect on emissions, according to research by (Y. J. Zhang et al., 2016b)

Governments are obligated to reduce CO_2 emissions and improve environmental quality in order to fulfil the concept of public benefits in regard to the environment. A key factor in deciding how much carbon emissions may be reduced is GE(*Luo: Influences on Environment Pollution by Local... - Google Scholar*, n.d.). Various incentive policies are implemented by governments to tackle the climate issue. These policies include environmental legislation, communication campaigns, innovation initiatives, and environmental levies, as reported by (Al-Mulali et al., 2022a). Still, the success of these policies rests largely on how well they are carried out, which depends on how well the government operates (J. Wen et al., 2021a)). (Glotko et al., 2020), contend that the pursuit of personal gain through the abuse of authority and lower productivity among government employees may make it difficult for ineffective governments to carry out plans. However, efficient governments may also more successfully enforce legislation meant to cut carbon emissions, which in turn lowers CO_2 emissions. Several empirical studies (Al-Mulali et al., 2022b; Chen et al., 2022; Kong et al., n.d.;

Polyakova et al., 2020). have confirmed the beneficial effect of GE on the reduction of carbon emissions. The vast majority of recent research, however, has used total CO_2 emissions as the dependent variable in their empirical analysis when examining the relationship between GE and carbon emissions. In short, they were primarily concerned with lowering the total quantity of carbon dioxide (CO_2) released into the atmosphere. Unfortunately, its effectiveness is not fully reflected in the decrease in total CO_2 emissions. When considering energy efficiency, carbon emission intensity is a more accurate measure than total CO_2 emissions (F. Zhang et al., 2020). It also cannot be disputed that there is an instantaneous decrease in CO_2 emissions when a nation reduces its output. However, utilizing this strategy to lower CO_2 emissions at the price of economic expansion is intolerable. Simultaneously, a decrease in carbon emission intensity denotes a decrease in the quantity of carbon dioxide released with a same level of production. Therefore, economic growth and carbon emission mitigation can be achieved simultaneously as long as there is a steady decrease in carbon emission intensity. In summary, pushing for lower carbon emission intensity is a more sensible approach to supporting coordinated advancements in the economy and environment than concentrating only on attaining a reduction in absolute terms of CO_2 emissions. Thus, by shifting the focus from total CO_2 emissions to carbon emission intensity and examining the effect of GE on carbon emission intensity, this study sets itself apart from previous research.

Efficiency in government has the capacity to lower CO_2 intensity in two ways. First, through encouraging innovation, increasing GE may lower the intensity of CO_2 emissions. Innovation is greatly enhanced by the effectiveness of the government. Initially, well-run governments are able to distribute funds for research and development (R&D) in an efficient manner, making sure that funds are allotted to the relevant disciplines. According to (D. Guo et al., 2022); this encourages a wide variety of innovative activities. Second, effective governments may ease the flow of information, technology, and cooperative innovation by establishing links between academic institutions, research centers, and commercial enterprises (Bai et al., 2014). To be more precise, competent governments may promote innovation through planning, coordinating, and supporting the development and expansion of innovation ecosystems (ibid). Moreover, competent governments often encourage creativity by creating intelligent intellectual property laws and ensuring that they are followed (J. Wen et al., 2021b)). Technology innovation is involved in two different aspects of the link between innovation and carbon emission intensity. Initially, it can improve manufacturing process energy efficiency, which can lower energy consumption per unit output and, as a result, CO_2 emissions per unit output—a phenomenon referred to as a fall in carbon emission intensity (Economics & 2018, 2018)); Second, putting technological innovation into practice—especially when it comes to green technology innovation like carbon capture and storage—can dramatically lower CO_2 emissions per unit output, which will lower CO_2 intensity (Shaw & Mukherjee, 2022)

Additionally, the government's focus on improving energy efficiency will shift the generation of energy toward renewables. Concerning the connection between energy efficiency and the energy consumption of governments on the one hand, competent governments can better determine their investment in RE projects in order to ensure that the investment funds are spent wisely, and this way they encourage RE development (Chebotareva et al., 2020). Moreover, efficient governments can craft and implement the needed measures for the promotion of the use of renewable sources just in the short run and moreover, these may include setting the RE ratios (R. Zhao et al., 2016)). Furthermore, to be noted is that (Ibarra-Yunez & PPrez-Henrrquez, 2017), the efficiency of the government system can stimulate RE consumption by creating the most cost-effective kind of competition before the integration of the new investments with the operation regulators of the energy systems and climate change institutions. In comparison with a non-renewable form of power, renewables produce lesser levels of CO_2 emission. Hence, where conventional energy is replaced with RE for power generation purposes, it becomes possible to reduce emissions per unit of the output, thereby lowering the carbon emission intensity. (Adams & Acheampong, 2019). Another question is whether governmental efficiency will affect on CO_2 emission intensity in terms of national income, economic freedom, democracy, and ruling party philosophy. To begin with, there is a correlation between the economic gap and the number of governments that prioritize environmental protection initiatives (Luo et al., 2023). The effect of GE on the intensity of carbon emissions may thus vary among these nations. essentially, the correlation between GE and the intensity of carbon emissions may be moderated by the degree of national affluence. Second, businesses in a free market are hesitant to invest in environmental protection because of the excessive demand for investment capital and the high risk involved (L. Yang et al., 2022). Reason being, the correlation between GE and intensity of carbon emissions may be moderated by economic freedom. Finally, we think that democracy moderates the influence of GE on carbon emission intensity, which is based on the observation (Obydenkova & Salahodjaev, 2016)) that nations with varying degrees of democracy tend to place various values on the environmental protection industry. Additionally, it was contended by (Neumayer, 2004) that the environmental protection industry receives varying degrees of attention from the left and right wing of politics. That being said, the effect of GE on the intensity of carbon emissions may change depending on which ideologically opposed political party is in control. For clarity's sake, the governing party's ideology can play the crucial role of mitigating the link between GE and carbon emission intensity.

Eventually, GE becomes a cornerstone of the pathway that emissions follow, the transition to RE, and the sustainable development of these countries. Through this process, policymakers will be able to establish solid governance structures, improve regulatory quality, and increase institutional capacity, thus making a framework conducive to emissions reductions, RE adoption, and sustainable development. Studies on government effectiveness, environmental governance, and policy innovation can feed into evidence-based decisions, create channels of cross-sectoral collaboration, and speed up progress toward a future where we all can enjoy a clean environment and low carbon pollution.

CO_2 Emissions in High and Low Emitting Economies

The economies become the principal actors of the global CO_2 emissions, where rapid industrialization, population growth, and increasing energy demand are the approaches followed by these economies during the process. Emphasizing a holistic approach to viewing the dynamics as well as drivers of CO_2 emissions in these economies is crucial in developing suitable strategies for fighting climate change and promoting sustainable development.

Comparative researches that demonstrate the trends in CO_2 emissions across a sample of high and low-emitting economies is a great wealth of knowledge that sheds light on the things that are influencing the trajectories of emissions. For instance, (Davis & Caldeira, 2010b) examine the carbon intensity of economic growth in China and India. They distinctly cover the role and influence of policy interventions, structural changes, and efficiency measures in reducing emission intensity. This report brought to light the fact that China managed to separate economic growth from the preservation of the environment, while India faces problems with curbing the growth of emissions because of its heavy reliance on coal and inefficient energy infrastructure.

Predicting CO_2 emissions is important because many factors could influence the number of emissions. To develop new models for predicting CO_2 emissions, some studies have been carried out recently, and some of these models are now being developed. According to (Y. Li et al., n.d.), China has been closely observing and forecasting its CO_2 emissions since the climate summit in Copenhagen. Regarding China's ability to satisfy its goal to reduce CO_2 intensity, various viewpoints and predicted outcomes have emerged. CO_2 emissions would be reduced by 45% if China sustains annual GDP growth rates of 7% and 6% over the 12th and 13th five-year plan periods, respectively, according to the projection model (Yuan et al., 2012) A 2021 study by (Islam et al., 2021) projected that CO_2 emissions in Bangladesh will peak at 58.97 million tonnes of oil equivalent (Mtoe) by 2040 using the logarithmic mean division index (LMDI) decomposition method. (Heydari et al., 2019) used grey wolf optimization (GWO) and a general regression neural network (GRNN) to assess the trend of CO_2 emissions in Italy, Canada, and Iran. The findings show that the suggested method performs better in terms of long-term CO_2 emission prediction accuracy. (Fang et al., 2018) used an enhanced Gaussian processes regression model in their investigation to forecast CO_2 emissions. They discovered that although the rate of increase in China's overall CO_2 emissions is expected to slow down. The report also indicates that it is anticipated that in the near future, the United States and Japan will be able to efficiently control their CO_2 emissions. Iran's CO_2 emissions for 2030 are predicted by the researchers, (S. M. Hosseini et al., 2019) using time series and regression analysis approaches. From their analysis, it appears unlikely that Iran would uphold its obligations under the Paris Agreement if it carries on with its existing business-as-usual operations. Furthermore, carbon dioxide (CO_2) emissions from the Chinese cement sector were projected by (Ofosu-Adarkwa et al., 2020), and their hybrid Verhulst-GM (1, N) method can 97% accurately estimate emissions. The long short-term memory (LSTM) model, according to (Ameyaw et al., 2019), anticipates a decline in China's CO_2 emissions from combustion until 2030. The intended nationally determined contributions of nations will be at risk if investments in RE are not increased, per their report. (Engineering & 2020, 2020) used kernel least squares (KLS), support vector machines (SVM), and long short-term memory (LSTM) models to forecast China's CO_2 emissions. The outcomes demonstrated that, in terms of accuracy, KLS performed better than other current techniques. (Y. Huang et al., 2019) conducted a pioneering study in which LSTM was utilized for the first time in China to forecast CO_2 emissions through principal component analysis and grey connection analysis. To forecast CO_2 emissions. (Amarpuri et al., n.d.)in India used a deep learning hybrid technique. For prediction, a convolutional neural network-long short-term memory (CNN-LSTM) deep learning model was used, which is a hybrid model. Simple exponential smoothing (SES) and autoregressive integrated moving average (ARIMA) models were used by(S. Fatima et al., 2019) to predict CO_2 emissions. Due to its lower fractional mean absolute error (FMAE) value when compared to other models, the ARIMA model was selected for prediction.

2.1. Theoretical Frameworks and Conceptual Models

The comprehension of the complex interrelationships between the GDP per capita, the increased utilization of RE sources of energy, the FF energy consumption, the PTS, etc., as well as the NRR productivity and the GE, will implicate a multidimensional analysis that combines different theories, frameworks, and findings of previous research into the subject. Here, we introduce some main theories and frameworks that help us understand how emissions are generated and their dynamic patterns and give some references to inform our conceptualization and study which is based on these theories and frameworks.

Environmental Kuznets Curve (EKC) Hypothesis

The Environmental Kuznets Curve hypothesis follows Simon Kuznets' theory, published in the 1950s, which suggests that environmental degradation phenomenon and economic development are factually correlated. This conception suggests the state when countries are in transition mode from a poor economic stage towards rapid industrialization and economic growth, the environment degradation dynamic initially worsens but later on improves once a certain level of financial growth has reached. The Kuznets curve is usually illustrated by a U-shaped line with the y-axis on the vertical axis meanwhile income levels on the horizontal axis. In the early phases of development, environmental degradation is accompanied by an increase in revenue. However, the drop in environmental degradation is accompanied by further income increased levels.

The introduction of the EKC hypothesis as a concept which helps to define the complicated interrelationship of economic progress and environmental quality made it popular. This can mean that, at the beginning of process of economic development, countries concentrate on industrialization and wealth production, which ignore the protective aspects of the environment. yet, for nations where the income levels are getting higher, and society is becoming wealthier, priorities may shift towards the protection of the environment leading to the adoption of clean technologies, more environmental regulations, and investments in sustainability projects.

The relevance of EKC in the research on comparative analysis between the highly CO_2 emitting and low emitting economies is extremely high as it could help determine the likely environmental degradation patterns within different stages of economic development. The EKC hypothesis implies that these countries with high CO_2 emissions and in the stage of emerging economies like China, India, and Brazil will experience worsening environmental degradation initially as they will undergo a rush of industrialization and urbanization. Even though at this early stage these economies depend on the development of infrastructure and the rise of per capita incomes there will be a change when cleaner energy sources are used and the level of concern will increase the environment leading to a decrease in CO_2 emissions. Deviating from the standard model is seen from economies with low CO_2 emissions that are situated in developed regions like the case of Sweden, Norway, and New Zealand EKC theory: they are expected to improve in terms of environmental quality as they reach higher income levels. These geographies have shown a strong dedication to sustainable development through capital investment in RE, implementation of strict environmental regulations, as well providing public awareness programs While for many countries the people's income is increasing and the output is high, however, low levels of CO_2 emission and environmental damage are been recorded.

Nevertheless, the validity of EKC theory to individual countries and a range of environmental indicators has triggered exchanges of debates over time. It is argued by critics that the EKC may overstate the connection between economic growth and environmental degradation. and at the same time, it may ignore the multi-faced driving forces that control the environment like technological innovation, population, and resource depletion. In addition, the EKC gives a primary role to income as the factor that determines ecology quality but ignores the role of social, political, and cultural factors that shape differently the outcome of the environment. Notwithstanding these criticisms, the EKC theory remains a valid theory for comprehending how economic growth may lead to pollution and the steps nations can take to achieve their development whilst preserving the planet. Through analyzing historical CO_2 emissions data, GDP per capita and the other indicators in the particular economies of the period between 1990 to 2020, scholars can check if the empirical data lies within the framework of the GNP Kuznets Curve theory. This comparative study may supply the essential understanding of the interaction between environmental sustainability and economic development, additionally, the decision about the high growth and minimizing the climate changes that the country where economically demand to this on the global scope.

The Environmental Kuznets Curve concept has been subject to a broad range of analysis and evaluation in both environmental economics and environmental policy discourse. Primarily (Grossman & Krueger, 1991), were the empirical early evidence, which contributed much to the foundation of the EKC hypothesis, in which case it was shown that there is a curvilinear connection between income levels and pollution amount. It has raised a lot of questions about why this relationship exists and what it might mean in terms of which strategies are effective in deterring climate change.

The following studies attempted to tweak and question the EKC framework, shifting focus to methodological issues and exploring the boundaries of applicability both in terms of the pollutants and contexts under consideration. This study (Dinda, 2004; Selden et al., n.d.)) came up with provoking conclusions regarding the connection between income and level of pollution and restated the point that the outcomes crucially depend on contextual factors like technological advancements and legislative regulation. The EKC theory has been strongly critiqued (Martínez-Zarzoso & Bengochea-Morancho, 2004; Stern, 2004b), mainly regarding its applicability to the current environmental pressures, notably global warming. In this regard, they argued that EKC can be too simplistic in terms of explaining the complex nature of environmental degradation and there are possibilities that it might miss the unequal distribution of environmental burden. The concept, notwithstanding these appraisals, has been utilized by proponents of the EKC theory, including (Dasgupta, 2009), a haven to formulate a framework meant to illustrate how economic growth and environmental quality are causally related. They put forward the EKC not as a universal truth behind all environmental problems but as a helpful guide containing valuable insights in the search for successful techniques in reaching the SDGs and the role of policy interventions as a tool for sorting out the inconsistencies in the EKC.

To sum up, EKC theory provides an interpretative tool to study the mechanism of the issue of the environment and growth. In this context, scholars are studying the dynamics of this relationship beginning with the initial stages of the development process across countries and at different stages of economic development, to better understand the reasons behind and the implications of ecological change, thereby assisting in creating more informed and effective policy tools for sustainable development.

Energy Transition Theory

Energy Transition Theory; a sociologist, William R. Freudenburg and colleagues' initial core argument in the late 1980s; also known as the transition theory or energy system transition theory, lends insights into the processes that societies employ to shift from a dominant energy system to another one (Freudenburg & Jones, 1991). This theory is based on the fact that energy transitions are not only about technical changes, but involve complex socio-technical systems where economic, political, socio-cultural, and environmental factors play an important role. The theory grows upon works of earlier sociologists and innovations studies to get the light of insights from the sociology of technology, institutional theory, and systems theory for explaining the complexities of the energy transition.

Basically, this theory is based on the fact that societies proceed through stages distinct from one another while they switch over to other kind of energy. Regarding energy phase transition phases, we usually mean the emergence of a new energy source, introduction of this new power into an existing structure, and displacement of the old power sources or transformation of them into a new power source which is planned as a result of the new energy source introduction.

In the field of the comparative analysis of economies that have high and low CO_2 emissions, the Energy Transition Theory represents a particular theoretical approach that underpins the dynamics of the growing RE markets and the gradual displacement of FF. As an illustration, countries like Sweden and Norway have undergone massive energy transformations, swapping coal for renewable sources like hydropower and wind energy. The drivers for these changes were not only technological advancement but also policy interventions, attitudes toward the sustainability of the public, and an abundance of resources. The next approach is developing countries like China and India that are in different stages of energy transition and dual challenges powerful industrialization and environmental sustainability. As these nations still are focused on using FF, they also build new RE facilities and apply laws to support clean energy development. Energy Transition Theory is more complicated and it is than economic growth and technological development while considering environmental sustainability.

Being that Energy Transition Theory accentuates systemic change and multi-level governance, the processes of establishing a successful energy transition would be highly facilitated. Here, cooperation between governments, enterprises, civil society, and international bodies to get rid of the barriers to RE adoption is key. Some of the barriers include lack of finance, legal hurdles, vested interests in the FF fuel industry, and so on. Energy Transition Theory can be applied to a comparative analysis of economies with high and low emissions of CO_2 by majoring in the drivers, barriers and outcomes of the energy transitions in different socio-economic situations (Bayulgen, 2020; Biresselioglu et al., 2020). This analysis can inspire policy decisions oriented at the speedy transition to sustainable energy, mitigating climate change, and featuring inclusive economic development.

Previous energy transition theories studies have been used to understand energy-related issues in many countries so we focus on the factors that promote energy transitions and the significance of their climate change and development agenda. Likewise, A (Geels, 2002) elaborate overview of Energy Transition Theory focusing on technological inventions, policy supports, and societal values, which are vital to energy transitions. As well, (Geels, 2014; Morgunova, 2021) use case studies to analyze the transitions of energy in different countries and they put into evidence the role of path dependence, policy-making feedback, and socio-technical regimes in the transition. Additionally, (Ameriekhtiar Abadi, 2023; Heldeweg, 2017) did further research about the policies and institutional frameworks which help the transitions of energy focusing on the need for a collaborative and concerted effort by stakeholders. Furthermore, the authors do (Adelekan et al., 2024; Geels & Schot, 2007) research focusing on what happens to society as energy transitions occur: their effect on job creation, income distributions, and regional competitors.

Eventually, the mentioned existing literature forms a firm base that makes it clear that the significance of energy transitions for sustainability and economic development is investigated. This research study builds on the previously existing knowledge and incorporates empirical data from diverse settings to contribute to the ongoing discussion around energy transition and policymaking for the purpose of the transition to a more sustainable energy system.

Innovation Diffusion Theory

Innovation Diffusion Theory, an idea that is said to have originated from the research of sociologist Everett Rogers in 1962, aims to explain the dynamics behind the spread of innovation among societies. This approach claims that the adoption of new things be them ideas, products, or practices initiates a series of events that follow a process with stages such as: learning, persuasion, decision, implementation, and confirmation.

The core part of the Innovation Diffusion Theory is represented by the innovation-decision process where different persons move through separate stages until they adopt some innovation. The stages of an adoption process are awareness about the innovation, its persuasiveness, deciding whether to accept or reject it and putting it in action to have proof of its effectiveness. These factors of diffusion rate include the nature of the innovation, the communication system, the setup of the social system, and the perception of the alternatives offered by the innovation in reference to the situations at hand.

In reference to the theme of the research paper on comparative analysis between high CO_2 emission economies and low CO_2 emission economies, Innovation Diffusion Theory presents critical points on the adoption and progression of RE technology and environmentally conservative practices. Specifically, countries that are at the forefront of the RE sector, such as Sweden and Norway, using their skill and experience in technologies and having appropriate policy environments and public support for sustainability measures have been able to lead such initiatives. By these measures, these countries have reached an impressive level of emission reductions that is CO_2 and environmental effects. Meanwhile, new economies including China and India experience difficulties in employing scale RE technologies although more and more people become aware of the role of sustainable development in the development process. Innovation Diffusion Theory offers answers to the obstacles to implementation, namely technology impediments, investment risks, and institutional boundaries. Upon grasping these factors, decision makers and stakeholders could design tailored interventions to promote highly the propagation of RE innovations and to keep up the sustainable development pathways.

Therefore, Communication and Social Networks are also emphasized in the Innovation Diffusion Theory of Communication Diffusion Theory (Cheng, 2022; Minishi-Majanja & Kiplang'at, 2005). Opinion leaders, early adopters, and innovation champions occupy an important position when it comes to social influence, interpersonal communication, and demonstration effects as far as others' adoption decisions are concerned. Through the process of engaging with the key sources, the policymakers can increase the effect of their policies supporting the deployment of RE and create a culture of sustainability within the society. Research on Innovation Diffusion Theory has been done before to investigate different settings from healthcare, agriculture, and technology to the environment and sustainability. Some researches (Delaportas, 2016; Evaluation & 2009, 2009; Mahajan et al., 1990) are fundamental that examine the more determinants of the diffusion process, and dimension of factors that make diffusion trajectories. Furthermore, works (Greenhalgh et al., 2004; Kreps, 2017) consider how social networks, communication paths and cultural elements impact the diffusion of innovations which are has lessons in sustainable development.

In summary, the Innovation Diffusion Theory gives a reasonable understanding of the acceptance and dissemination of RE technology and green practices in different socio-economical contexts. Through the use of lessons learned from this theory, researchers are capable of conducting the comparative study of economies with high and low CO_2 emissions. They are able to identify opportunities and challenges that are associated with the green innovation, as well as the low carbon transition to the sustainable energy future.

Technological Innovation Systems (TIS) Framework

The technological Artificial Systems (TIS) framework looks at technology and innovation as a whole as opposed to in silos which is how STS systems function. Coming from evolutionary economics and innovation research, the TIS models give attention to the actors, institutions, and technology aspects as the key factors in driving innovation tendencies (Boons & McMeekin, 2019) In the context of RE utilization and reduction of greenhouse gasses, this framework portrays the elements of critical policies interventions, research and development efforts, and technology diffusion mechanisms in the TIS mapping framework investigates the innovation climate surrounding various RE technologies, and that is how it unveils determinants of technologies adoption and spread across economic allocation situations.

The TIS framework incorporates several essential elements that adjust themselves and play out in the intricate interplay to influence the innovation processes. These include:

1**. Knowledge Creation and Diffusion**: This factor is determined through the research and development activities, as well knowledge diffusion through partnerships, collaboration, and information sharing is considered essential in technology innovations within industries of technologies. The concept of knowledge creation and dissemination in RE technologies mainly includes scientific researches, experimentations, and innovations as well as academic writings, patenting, conferences and cooperative ventures (Bergek et al., 2008; Markard et al., 2015)

2**. Actor Networks and Interactions:** Small entities that make up the technology innovative system (TIS), that is industries, research bodies, government agencies, non-governmental organizations, and consumers, create different kinds of relationships that affect innovation. Actors involved in these activities range from business entities conducting research and development, technology commercialization, and policy advocacy to market creation which determines the framework in which technological change takes place (Smith et al., 2010)

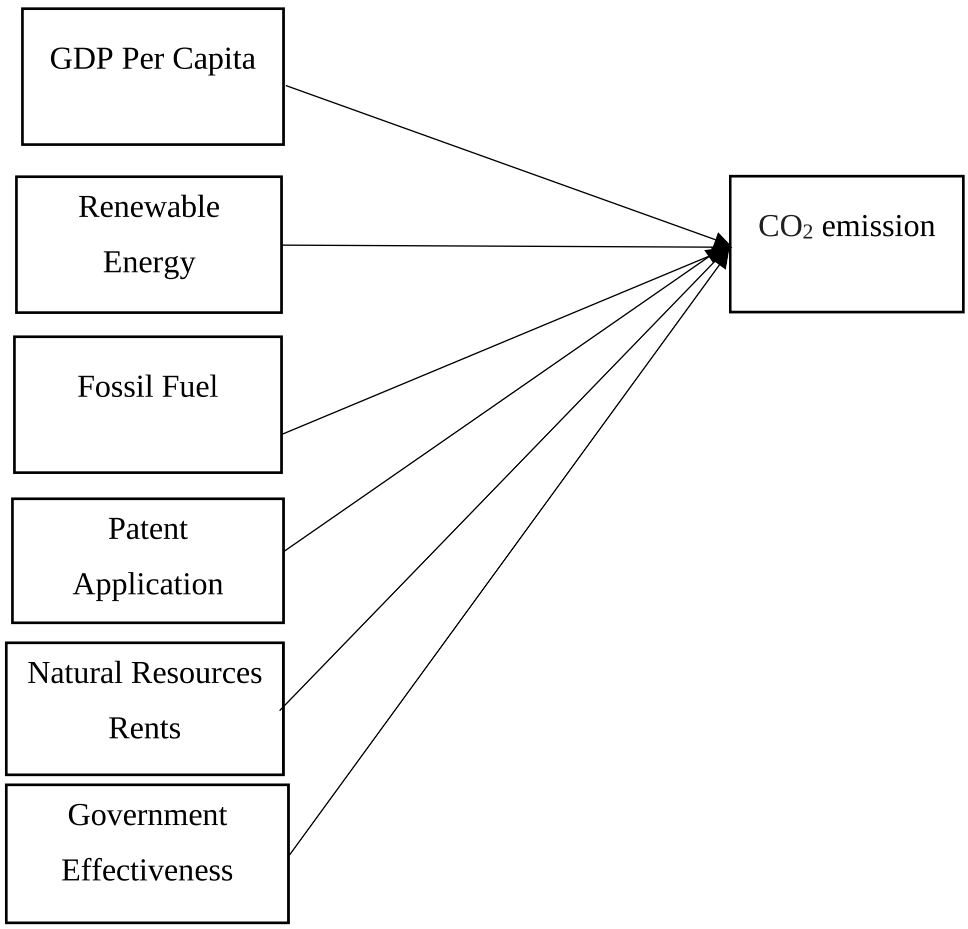
3. **Institutional** Context: The institutional framework, such as policy framework, regulatory regime, and intellectual property (IP) rights regime, is of utmost importance in shaping motivators and results in the technologies innovation support system. Empowering measures, for instance, feed-in tariffs, RE mandates, and research grants can give impetus to progress with some of the renewable technologies by helping to innovate and hike the market share of such technologies, whereas on the other hand, regulations and market distortions have the capability of hindering the process (Hekkert et al., 2007; Markard et al., 2012)

4. **Technological Trajectories**: TISs can be traced with their evolving technology trajectories representing the change in the technology field what sub-area is developing and at what rate. Relating to RE, the technical trajectories comprise of an improvement of solar photovoltaics, wind power, bioenergy, and hydropower just to name a few, each of which has for itself its own process of innovation, vision of the market and hurdles associated with its deployment (Foxon, 2014)

2.2. Conceptual Model

Variable under investigation: CO_2 Emissions.

Independent variables include gross domestic product per capita, renewable energy, fossil fuels, patent applications, rents from natural resources, and the efficiency of the government.



2.3 A Brief Summary of the Available Literature

Table 1. A Summary of the Research Conducted

Author	**Place of study**	**Research objective**	**Time of study**	**methodology**	**Brief result**	**Brief policy recommendations**
Sovacool, B.K. (2015)	Global	investigated how policy tools—like feed-in tariffs, renewable portfolio standards, and tax breaks—affect global investment in RE infrastructure.	2014	Literature review	Countries with supportive policy frameworks tend to have higher shares of RE in their energy mix, leading to reductions in CO_2 emissions and other environmental benefits.	In an effort to speed up the transition to renewable energy sources and attract investors, shift to low-carbon power systems, put in place enabling policy frameworks, for example, financial incentives, renewable portfolio requirements, and feed-in tariffs.
Lin & Li (2015); Sattich et al., (2021)	China & EU	Comparing RE policies and outcomes between China and the	2012-2020	Comparative analysis	China has made significant investments in RE	Address challenges in grid integration and institutional barriers to

		European Union, analyzing political, economic, and technological factors shaping RE trajectories in each region.			infrastructure but faces challenges in grid integration and institutional barriers.	facilitate the transition to RE in China.
Sinha & Shahbaz (2017)	India	Examined the socio-economic implications of RE adoption in India, emphasizing reduced CO_2 emissions and positive socio-economic impacts such as job creation and income redistribution.	1971-2015	Statistical analysis	RE adoption in India offers dual benefits of reduced CO_2 emissions and positive socio-economic impacts including job creation and income redistribution.	Implement policies to promote RE adoption in India, harnessing its potential for reducing CO_2 emissions and fostering socio-economic development.
Jebli et al. (2019)	Central & South America	investigated the links between the use of RE, travel, economic expansion, FDI, and CO_2 emissions.	1995–2010	Statistical analysis	examined the causal connections between the use of RE, travel, economic expansion, and FDI,	Develop policies to promote RE consumption, sustainable tourism, and foreign direct investment to foster GDP growth while mitigating

					together with CO_2 emissions in South and Central American countries.	CO_2 emissions in Central and South American countries.
Nathaniel & Iheonu (2019)	Africa	examined the connection between Africa's CO_2 reduction and the usage of RE and non-RE energy sources using the AMG estimation technique.	1990–2014	Statistical analysis	Utilizing the AMG estimation technique, researchers examined the connection between the use of RE and non-RE resources and CO_2 reduction in Africa.	Implement policies to promote RE consumption and CO_2 abatement strategies to mitigate environmental impact in Africa.
T. Fatima et al. (2020)	Leading emitting countries	investigated how growing CO_2 emissions in the top emitting nations are affected by RE and non-RE energy sources.	1980-2014	Statistical analysis	Investigated the role of RE and non-RE energy in rising CO_2 emissions in leading emitting countries.	Implement policies to promote RE adoption and mitigate CO_2 emissions in leading emitting countries.
A. Khan et al. (2021)	Belt and Road Initiative	evaluated how financial operations, technological	2000-2014	Statistical analysis	Investigated the impacts of technology advancement,	Implement policies to promote technological

	(BRI) countries	developments, and foreign direct investment affected the development of renewable and non-RE sources, as well as the levels of CO_2 emissions in countries that are part of the BRI both short and long-term.			funding, and FDI on renewable energy, non-renewable energy, and carbon dioxide emissions in BRI nations.	innovation, finance, and FDI to support RE adoption and mitigate CO_2 emissions in BRI countries.
Acheampong et al. (2021)	Sub-Saharan Africa	Examined the causal relationship over time between institutions, RE, CO_2 emissions, and economic growth in nations located in SSA.	1960-2017	Statistical analysis	investigated the causal relationship between institutions, RE, carbon emissions, and GDP growth in SSAC over an extended period of time.	Develop policies to strengthen institutions, promote RE adoption, and mitigate CO_2 emissions to support sustainable GDP growth in SSAC.
Abban et al. (2022)	African oil-producing economies	Argued for transitioning to energy from	2000-2019	Argumentative analysis	Argued for the benefits of shifting toward	Advocate for policies promoting RE adoption and economic

		sustainable sources to improve natural ecosystems and expansion of the economy of African countries that produce oil.			renewable sources of energy to improve natural ecosystems and GDP growth in oil-producing African countries.	diversification to enhance sustainability and economic growth in African oil-producing economies.
Mehmood (2021)	G11 economies	considered factors including education, GDP, NR, and FDI for the G11 economies when examining the impact of RE on CO_2 emissions. .	1990-2019	Statistical analysis	Examined the effects of RE on G11 economies' CO_2 emissions taking variables like education, GDP, NR, and FDI into account.	Develop policies to promote RE adoption and address factors such as education and GDP to mitigate CO_2 emissions in G11 economies.
S. Abbas et al. (2022)	BRICS countries	investigated the link between BRICS nations' CO_2 emissions and the rise of RE, market regulation, and environment-	1990-2020	Statistical analysis	Examined the impact on CO_2 emissions in BRICS nations of renewable energy development, market	Help the BRICS nations reduce their CO_2 emissions by encouraging RE development, market regulation, and green innovation.

		related innovation.			regulation, and environmental innovation.	
Apergis et al. (2023)	Uzbekistan	Investigated the connection between Uzbekistan's utilization of renewable and non-RE sources and CO_2 emissions between 1985 and 2020.	1985–2020	Statistical analysis	Investigated the link between CO_2 emissions and the use of RE and non-RE in Uzbekistan .	Implement policies to promote re-consumption and reduce reliance on non-RE sources to mitigate CO_2 emissions in Uzbekistan.
H. Khan et al. (2020)	Global	employed panel quantile regression to conduct research on the connection between the use of RE, carbon emissions, and financial development in 192 countries.	1980-2018	Panel quantile regression	Found heterogeneous effects across quantiles. RE negatively affects CO_2 emissions, while financial development has a positive effect. Carbon dioxide negatively affects RE.	Implement policies that promote RE consumption and financial development to mitigate CO_2 emission while addressing heterogeneous effects across countries.
Long et al. (2015)	China	studied the effects on	1977–2011	Statistical analysis	Reported that RE	Promote policies supporting the

		economic growth and carbon dioxide emissions in China of employing renewable energy versus non-renewable energy.			consumption significantly reduced CO_2 emissions in China.	adoption and development of RE sources to mitigate CO_2 emissions and support sustainable economic growth in China.
Jaforullah & King (2015)	USA	Investigated the impact of RE consumption on CO_2 emissions in the USA.	1985-2002	Statistical analysis	Found evidence that RE consumption reduces CO_2 emissions in the USA.	Encourage investment in RE infrastructure and technologies to reduce CO_2 emissions and promote environmental sustainability in the USA.
Paramati, Mo, et al. (2017a)	Next 11 countries	Examined the impact of RE consumption on CO_2 emissions in the Next 11 countries.	1991-2012	Statistical analysis	Reported similar findings to Long et al. (2015), showing that RE consumption significantly reduces CO_2 emissions.	Advocate for the adoption of RE sources to mitigate CO_2 emissions and promote sustainable development in the Next 11 countries.

Menyah & Wolde-Rufael (2010a)	USA	Explored the impact of nuclear and RE consumption on CO_2 emissions in the USA.	1960–2007	Statistical analysis	Studies have demonstrated that the use of nuclear energy results in a significant decrease in CO_2 emissions; on the other hand, the use of RE sources has no discernible effect on lowering CO_2 emissions in the US.	Promote investment in nuclear energy as a means to reduce CO_2 emissions while further research is conducted to enhance the effectiveness of RE sources in reducing emissions.
Bloch et al. (2015a)	China	Investigated the impact of coal and RE consumption on CO_2 emissions in China.	2000-2011	Statistical analysis	Discovered that in China, the use of coal increases CO_2 emissions, whilst the use of RE decreases them.	Implement policies to transition away from coal towards RE sources to reduce CO_2 emissions and promote environmental sustainability in China.
Al-Mulali et al. (2016)	Kenya	Examined the impact of fossil fuel and RE	1980–2012	Statistical analysis	Determined that in Kenya, the use of FF	Encourage policies to promote the

		consumption on CO_2 emissions in Kenya.			increases CO_2 emissions, but the use of RE sources considerably decreases these emissions.	adoption of RE sources to mitigate CO_2 emissions and reduce environmental degradation in Kenya.
Dogan & Seker (2016)	European Union	This research examines the relationship between CO_2 emissions and 15 EU member states' energy consumption patterns, broken down by renewable and non-renewable sources. .	1980–2012	Statistical analysis	Documented that using RE has been shown to significantly reduce CO_2 emissions; nevertheless, using non-RE sources has caused these emissions to increase. found that the amount of RE consumed and the amount of carbon dioxide emitted are inversely related.	Implement policies to incentivize the adoption of RE sources while transitioning away from non-RE to mitigate CO_2 emissions and promote sustainable development in the European Union.

Bhattacharya et al. (2017)	Developed & Developing Countries	Analysed 85 nations' GDP growth and CO_2 emissions in relation to RE usage and institutions. .	1991–2012	Statistical analysis	Reported that RE consumption and Institution has an effect that reduces CO_2 emissions while increasing GDP.	Promote policies that support the adoption of RE sources and institutions that facilitate sustainable boost global economic growth while cutting CO_2 emissions in both rich and poor nations.
Paramati, Mo, et al. (2017b)	G20 economies	Discovered that among a sample of G20 economies, RE usage boosts GDP growth while decreasing CO_2 emissions. .	1991-2012	Statistical analysis	Reported similar findings to Long et al. (2015) and Jaforullah & King (2015), demonstrating that RE consumption reduces CO_2 emissions and fosters economic growth in G20 economies.	Encourage G20 economies to prioritize the adoption and development of RE sources to achieve sustainable economic growth while mitigating CO_2 emissions and addressing climate change challenges.

Apergis & Payne (2009)	Central America	Examined the causal link using a panel VECM between GDP growth, consumption of FF, and CO_2 emissions.	1971–2004	Panel VECM model	proved beyond a reasonable doubt that economic growth and CO_2 emissions are correlated, with the pattern being an inverted U. There is a bidirectional relationship between the use of FF and CO_2 production, as well as between economic development and FF consumption.	Focus on sustainable development and promote energy efficiency. Channel FDI into environmentally friendly and technology-intensive industries to improve environmental quality.
Jalil & Mahmud (2009)	China	Explored the long-run equilibrium association between CO_2 emissions, fossil energy consumption,	1975–2005	Time series analysis	Proven the EKC theory. A direct correlation between rising GDP and CO_2 emissions was established.	Implement policies to promote sustainable economic development, enforce environment-

		economic growth, and foreign trade using time series data.				friendly regulations, and control air pollutant emissions to preserve ecosystems.
Seker et al. (2015)	Turkey	Used an ARDL model to look at how FDI, economic growth, and FF usage affected CO_2 emissions.	1974–2010	ARDL model	Verified the accuracy of the EKC theory. Discovered causal connections among the usage of fossil energy, economic growth, FDI, and the emission of CO_2.	Focus on sustainable development, promote energy efficiency, and channel FDI into environmentally friendly and technology-intensive industries.
Sulaiman et al. (2013)	Malaysia	Investigated the short-run and long-run dynamics between fossil energy, economic development, and CO_2	1980–2009	Statistical analysis	Disaggregated energy data supported the EKC curve, while aggregated data did not.	Consider disaggregated energy data to better understand the relationship between energy consumption, economic

		emissions using aggregated and disaggregated energy data.				development, and CO_2 emission.
Shahbaz et al. (2014)	Tunisia	Inspected the EKC in Tunisia and its association with economic development, fossil energy consumption, trade openness, and CO_2 emission.	1971–2010	ARDL bound test approach	Confirmed the EKC curve. Found long-run equilibrium between economic development, fossil energy consumption, trade openness, and CO_2 emission.	Promote sustainable economic development through the implementation of environment-friendly regulations and control of air pollutant releases.
Ahmad et al. (2016)	India	Examined the long-term and short-term relationship between India's CO_2 emissions, economic development, and fossil energy consumption.	1971–2014	Statistical analysis	Validated the EKC hypothesis in India. Found positive impact of fossil energy consumption on CO_2 emissions. Discovered feedback effect between CO_2 emissions	Implement policies to promote energy efficiency and sustainable development.

					and economic development.	
Kanjilal & Ghosh (2013)	India	Authorized the presence of the EKC and identified a "regime-shift" or "threshold" integration in the Indian economy.	1971–2008	Statistical analysis	Validated the Environmental Kuznets Curve (EKC) for the Indian economy. Discovered that CO_2 emissions exhibit high elasticity in relation to GDP per capita and energy consumption.	Implement measures to control CO_2 emission and promote sustainable economic growth.
Nasir & Ur Rehman (2011)	Pakistan	Investigated the link among income, CO_2 emission, fossil energy consumption, and foreign trade in Pakistan using the Johansen method of co-integration.	1972–2008	Co-integration analysis	Confirmed the existence of the EKC curve in Pakistan. Found positive impact of fossil energy consumption and foreign trade on CO_2 emission.	Implement policies to promote sustainable development and control CO_2 emission.

Javid & Sharif (2016)	Pakistan	Analyzed the impacts of financial development, real income, energy consumption, and trade openness on CO_2 emissions in Pakistan.	1972–2013	Statistical analysis	Confirmed the EKC theory in Pakistan. Identified economic growth, fossil energy consumption, and financial development as crucial contributors to environmental degradation.	Focus on sustainable economic policies and environmental conservation efforts.
Pao & Tsai (2011)	BRIC nations	Investigated the relationship between economic development, fossil energy, FDI, and CO_2 emissions in the BRIC countries over the long term.	1992-2007	Co-integration and Granger causality	Confirmed the validity of the EKC hypothesis in BRIC nations. Found positive impact of FDI on CO_2 emissions. Discovered bidirectional causality between CO_2 emissions and FDI.	Manage foreign direct investment (FDI) to promote energy efficiency and reduce air pollution without compromising competitiveness.

Mirza & Kanwal (2017)	Pakistan	Examined the dynamic link among economic development, fossil energy usage, and CO_2 emissions in Pakistan.	1971–2009	Statistical analysis	Identified two-way causality between fossil energy, carbon dioxide, and economic development in Pakistan.	Implement measures to reduce FF dependency and promote RE sources.
Nkengfack et al. (2019)	Algeria, Egypt, South Africa	Examined the causal association between fossil energy, CO_2 emissions, and economic development in Algeria, Egypt, and South Africa.	1971–2015	ARDL approach, Toda-Yamamoto test	Aggregate energy and economic development positively influenced CO_2 emissions in the short and long run. Fossil energy and coal consumption significantly contributed to CO_2 emissions.	Implement measures to promote RE sources and reduce dependence on FF to mitigate CO_2 emissions.
Saidi & Hammami (2016)	58 nations	Examined the association between fossil energy, CO_2 emissions, and economic	1990–2012	Dynamic simultaneous-equation panel data analysis	Found a bidirectional association between fossil energy, CO_2 emissions, and	Implement policies to reduce FF consumption and promote sustainable economic

		development across various regions using dynamic simultaneous-equation panel data.			economic development in all panels. Identified a unidirectional causality from CO_2 emissions to economic development in the Caribbean and Latin American region.	development to mitigate negative environmental impacts.
Awan & Azam, 2022	G-20 Economies	Examine nuances in the relationship between GDP per capita and CO_2 emissions, moving beyond traditional frameworks like the EKC hypothesis.	1993-2017	LM booststap approach	Nuanced insights provided, challenging traditional views on the GDP- CO_2 emissions relationship.	Encourage further exploration of alternative perspectives beyond the EKC hypothesis to inform more nuanced policy interventions.
Cole et al., 1997	OECD	Investigate the direct relationship between GDP per capita and CO_2 emissions, likely with	1997	GLS REGRESSION	Found direct evidence supporting a strictly monotonic relationship between	Consider implementing policies targeting emissions reduction regardless of GDP growth to address

		empirical analysis and theoretical discussions.			GDP/capita and CO_2 emissions.	environmental concerns.
Nuţă et al., 2024	European and Asian	Examine the GDP per capita – CO_2 emission relationship through the viewpoint of the EKC hypothesis. .	1995-2019	Panel data analysis	Found evidence supporting the EKC hypothesis, indicating an inverted U-shaped relationship between GDP per capita and environmental degradation.	Emphasize the importance of policy interventions in mitigating environmental degradation even within the framework of the EKC hypothesis.
Zoundi, 2017	25 African countries	Use DOLS and SGMM to investigate the correlation between GDP per capita and CO_2 emissions. .	1980-2012	DOLS and System-GMM methods	Figured out that CO_2 emissions and GDP per capita form a U-shaped connection.	Implement policies targeting emissions reduction beyond a certain income level to mitigate environmental degradation.
Tong et al., 2020	China	Employ integrated assessment models to simulate the impacts of alternative	2015-2050	Integrated assessment models	Emphasized the importance of early action and ambitious mitigation efforts in	Advocate for early action and ambitious mitigation efforts to avoid dangerous levels of climate change.

		development pathways on global emissions levels.			avoiding dangerous levels of climate change.	
Apergis & Payne (2010)	20 OECD countries	Investigated the nexus between RE consumption and GDP growth.	1985–2005	Causality analysis	Found a positive impact of RE consumption GDP growth and bidirectional causality between the two variables in OECD countries.	Encourage RE production through policies such as tax credits, RE portfolio standards, and the expansion of RE systems to support economic growth.
Menyah & Wolde-Rufael (2010)	USA	Examined causality between GDP growth and RE consumption in the USA.	1960-2014	Causality analysis	The relationship between GDP growth and RE consumption in the US was determined to be unidirectional.	Develop policies to stimulate GDP growth, which may, in turn, lead to increased adoption of RE.
Salim & Rafiq (2012)	6 emerging economies	Analyzed the impact and causality between GDP	1980–2006	Causality analysis	There appears to be a two-way causation between	Implement policies to stimulate GDP growth and

		growth and RE consumption in six emerging economies.			renewable energy consumption and GDP growth in Turkey, Brazil, China, and the Philippines, while in India and Indonesia, it's seen as a one-way causality.	encourage RE adoption in emerging economies to support sustainable development.
Ocal & Aslan (2013)	Turkey	Investigated the link and causality between RE consumption and GDP growth in Turkey.	1990–2010	Causality analysis	Found a negative impact of RE consumption GDP growth in Turkey and unidirectional causality from economic growth to RE consumption.	Address barriers to RE adoption and develop policies to stimulate economic growth in Turkey.
Payne (2009)	USA	Investigated the cause-and-effect connection between the consumption of RE and GDP	1949–2006	Causality analysis	Did not find any evidence that increased consumption of RE contributed to economic	Promote further research and development to understand the factors influencing RE adoption and

		growth in the US			growth in the US. .	economic growth in the USA.
Inglesi-Lotz (2016)	34 OECD countries	Investigated the impact of RE consumption on GDP growth in OECD countries.	1990-2010	Regression analysis	Discovered that in OECD countries, consumption of RE sources significantly and favourably affects economic growth.	Encourage policies to support RE adoption to foster economic growth in OECD countries.
Gozgor (2018)	USA	Explored the impact of RE consumption and economic complexity on economic growth in the USA.	1965–2016	Regression analysis	Found a positive impact of RE consumption and economic complexity on economic growth in the USA.	Develop policies to promote RE consumption and enhance economic complexity to support economic growth in the USA.
Gozgor et al. (2018)	27 OECD countries	Investigated the impact of renewable and non-RE consumption and economic complexity on economic	1990–2013	Regression analysis	Found a positive impact of renewable and non-RE consumption and economic complexity on	Implement policies to promote both renewable and non-RE consumption and enhance economic complexity to

		growth in OECD countries.			economic growth in OECD countries.	support economic growth in OECD countries.
H. Y. Yang (2000)	Taiwan	Examined the aggregate and disaggregate causal link between energy use and economic growth.	1954–1997	Causality analysis	Discovered a direct correlation between Taiwan's economic growth and their consumption of natural gas.	Develop policies to encourage natural gas consumption as it appears to positively impact economic growth.
Lotfalipour et al. (2010)	Iran	Investigated how disaggregated energy usage relates to economic growth.	1967-2007	Causality analysis	The correlation between Iran's economic growth and its use of natural gas was similarly found to be unidirectional.	Develop strategies to enhance natural gas consumption to stimulate economic growth.
Hu & Lin (2008)	Taiwan	Link between energy consumption and GDP growth as it is	1982–2006	Causality analysis	The correlation between Taiwan's economic growth and its	Policies should focus on fostering a symbiotic relationship between natural gas consumption

		measured at the aggregate level .			usage of natural gas was shown to be bidirectional.	and economic growth.
Saboori et al. (n.d.)	Malaysia	Looked into the disaggregate level relationship between natural gas usage and economic growth.	1980-2009	Causality analysis	In Malaysia, they observed a short-run unidirectional causality between natural gas consumption and economic growth, as well as a long-run bidirectional causality.	Encourage policies that promote natural gas consumption for short-term economic growth, while ensuring sustainability for long-term benefits.
Bildirici & Bakirtas (2014)	BRIC-TS countries	Analysed the connection between GDP growth and individual energy usage.	1980–2011	Causality analysis	Found bidirectional causality between natural gas consumption and economic growth in Brazil, Russia, and Turkey.	Implement policies to foster natural gas consumption as it contributes to economic growth in BRIC-TS co

Bekun (2019)	Romania	Used NAR-DLM to examine the connection between energy intensity, CO_2 emissions, renewable energy, and GDP growth. .	1990-2014	NAR-DLM analysis	Energy intensity and CO_2 emission negatively affect economic growth and positively affect RE consumption.	Implement policies to reduce energy intensity and CO_2 emission while promoting RE consumption.
Aydoğan & Vardar (2020)	E7 countries	Examined the role of RE, economic growth, and agriculture on CO_2 emissions using the EKC model.	1990-2014	EKC model analysis	RE consumption positively impacts economic growth and negatively affects CO_2 emissions.	Promote RE consumption to foster economic growth and mitigate CO_2 emissions.
Afroz & Muhibbullah (2022)	Malaysia	Investigated dynamic linkages between NRE, RE, and economic growth in Malaysia using nonlinear ARDL approach.	1980-2018	Nonlinear ARDL analysis	NRE consumption positively affects economic growth, while RE consumption negatively affects it.	Promote a policy mix that supports both RE and technological innovation to mitigate environmental degradation.

Hieu & Mai (2023)	Developing countries	Investigated the impact of RE on economic growth in developing countries using MMQR estimations.	1990-2020	MMQR estimations	RE consumption positively affects economic growth, while NRE consumption negatively affects it.	Implement policies to promote RE consumption to foster economic growth.
Kartal et al. (2023)	UK	Investigated the asymmetric effect of political stability on production-based CO_2 emissions using nonlinear ARDL and frequency domain causality model.	1995-2018	Nonlinear ARDL and causality model analysis	Political stability positively affects CO_2 emissions, while RE consumption negatively affects them.	Implement policies to promote political stability and RE consumption to reduce CO_2 emissions.
Koçak & Ulucak (2019)	OECD countries	Examined the effects of R&D expenditures on CO_2 emissions.	2003–2015	STIRPAT model	Due to advancements in energy efficiency and FF, a strong positive correlation was discovered	Emphasize the importance of directing R&D expenditures towards technologies that reduce CO_2 emissions rather

					between R&D spending and CO_2 emissions.	than FF development.
Y. J. Zhang et al. (2017a)	China	Investigated the effect of environmental innovations on CO_2 emissions using the SGMM technique.	2000–2013	SGMM technique	Discovered that technological advancements in the areas of resource management, information dissemination, and environmental protection significantly cut down on China's CO_2 emissions.	Encourage the implementation of environmental innovations to reduce CO_2 emissions and promote sustainable development in China.
Mensah et al. (2018)	28 OECD countries	Used the STIRPAT model to look into how innovations affect CO_2 emissions.	1990–2014	STIRPAT model	Found that innovation plays a crucial role in mitigating CO_2 emissions.	Promote policies that inspire new approaches to combating climate change and cutting down on CO_2 emissions.
Johnstone et al. (2010)	25 OECD countries	Examined the effects of	1978–2003	Panel data	Results showed that	Boost innovation in the RE sector

		environmental policies on technological innovation in RE using panel data.			PTS and the introduction of new RE technology were significantly impacted by public policy.	by urging governments to invest in research and development and enact regulations that are favourable to the industry.
Yu et al. (2016)	Chinese provinces	Investigated the role of renewable NR in mitigating CO_2 emissions and other greenhouse gases in Chinese provinces using a bio-perspective method (energy analysis).	2007–2015	Energy analysis	Found that renewable NR plays a prominent role in mitigating the negative impact of CO_2 emissions in some Chinese provinces, with Qinghai Province ranking first in resource sustainability.	Promote the sustainable management and utilization of renewable NR to mitigate CO_2 emissions and improve environmental sustainability in provinces.
L. Zhang et al. (2021)	Pakistan	Investigated the impact of NR on environmental degradation in Pakistan using ARDL models.	1985–2018	ARDL models	Found that the abundance of NR leads to a decrease in CO_2 emissions in Pakistan, indicating a negative	Encourage policies that promote sustainable utilization of NR and prioritize environmental protection to

					relationship between NR and CO_2 emissions.	mitigate CO_2 emissions and reduce environmental degradation in Pakistan.
Dong et al. (n.d.)	BRICS countries	Investigated the relationship between gas NR and environmental quality in BRICS countries using AMG long-run techniques.	1985–2016	AMG long-run techniques	Found a negative correlation between renewable-gas NR and CO_2 emissions in the long run, indicating that abundance of renewable-gas NR led to an increase in environmental sustainability during the study period.	Encourage policies that promote the utilization of renewable-gas NR to enhance environmental sustainability and reduce CO_2 emissions in BRICS countries.
I. Khan et al. (2022)	United States	Investigated the impact of NR on environmental degradation in the United States using GMM models.	1971–2016	GMM models	Showed that the abundance of NR leads to increased environmental sustainability over the study period, indicating a	Advocate for policies that promote sustainable management of NR to enhance environmental sustainability and mitigate

					negative relationship between NR and environmental degradation.	environmental degradation in the United States.
Badeeb et al. (2020)	Malaysia	Examined the impacts of NR on CO_2 emissions in Malaysia using the ARDL model.	1970–2016	ARDL model	Results showed that NR had the opposite effect on environmental degradation as expected throughout the study period, casting doubt on the theory that NR reliance directly contributes to degradation.	Support policies promoting sustainable utilization of NR to mitigate CO_2 emissions and reduce environmental degradation in Malaysia.
Z. Wang et al. (2020)	China	Investigated the influence of NR on CO_2 emissions in China using the Slacks-Based Measure with windows	2003–2016	Slacks-Based Measure	Presented evidence of a negative relationship between the abundance of NR and the efficiency of	Encourage policies that will make better use of China's natural resources in order to lessen the country's carbon footprint and make

		analysis approach.			CO_2 emissions, indicating that greater natural resource abundance leads to lower efficiency of CO_2 emissions.	it more environmentally sustainable.
Danish, Baloch, Mahmood, et al. (2019b)	BRICS countries	Used the AMG model to study the connection between NR and CO_2 emissions in BRICS nations.	1990–2015	AMG model	Found that NR increases CO_2 emissions in Brazil, China, and India while helping to reduce pollution in Russia due to its large resource abundance.	Implement policies to promote sustainable utilization of NR and mitigate CO_2 emissions in Brazil, China, and India, while ensuring efficient resource management in Russia.
X. Li et al. (2022)	China	Examined the impact of increased use of NR on environmental pollution in China using the STIRPAT model.	2003–2014	STIRPAT model	Concluded that the increased use of NR leads to environmental pollution in China.	Implement regulations and measures to promote sustainable resource management and mitigate

						environmental pollution in China.
Joshua and Bekun (2020)	South Africa	Investigated the relationship between increased use of NR and CO_2 emissions in South Africa using the ARDL model.	1970–2017	ARDL model	Concluded that the increased use of NR leads to increased CO_2 emissions in South Africa.	Develop policies aimed at promoting sustainable utilization of NR and reducing CO_2 emissions in South Africa.
S. T. Hassan et al. (2019)	Pakistan	Examined the impact of increased use of NR on CO_2 emissions in Pakistan using the ARDL and VECM models.	1971–2017	ARDL and VECM models	Concluded that the increased use of NR leads to increased CO_2 emissions in Pakistan.	Implement measures to promote sustainable management of NR and reduce CO_2 emissions in Pakistan.
Kwakwa et al. (2019)	Ghana	Studied the dynamic links between NR and CO_2 emissions in Ghana using the STIRPAT model.	1971–2013	STIRPAT model	Found a positive link between NR and CO_2 emissions in Ghana.	Develop strategies to promote sustainable utilization of NR and mitigate CO_2 emissions in Ghana.
Shen et al. (2021)	China	Investigated the impact of NR on CO_2 emissions in China using the	1995–2017	ARDL approach	During the study period, a positive association was found	Implement measures to promote sustainable utilization of NR

		ARDL approach.			between NR and CO_2 emissions in China.	and mitigate CO_2 emissions in China.
Ulucak & Bilgili (2018)	OECD countries	Examined the impact of NR on CO_2 emissions in OECD countries using the AMG model.	1980–2016	AMG model	Stated that the extraction of NR in OECD countries significantly contributes to increased CO_2 emissions.	Develop policies aimed at promoting sustainable resource management and reducing CO_2 emissions in OECD countries.
M. K. Khan et al. (2021)	BRI countries	Studied the dynamic links between NR and CO_2 emissions in BRI countries using the GMM model.	1990–2016	GMM model	Found a positive link between NR and CO_2 emissions in BRI countries.	Implement strategies to promote sustainable management of NR and mitigate CO_2 emissions in BRI countries.
M. Ahmad et al. (2020b)	North-western China	Examined the relationship between NR and CO_2 emissions in north-western China using the FMOLS method.	1995–2017	FMOLS method	Concluded that NR and CO_2 emissions have a positive relationship in some provinces of north-western China.	Develop region-specific policies to address CO_2 emissions and promote sustainable use of NR in north-western China.

Bekun et al. (2019)	EU economies	Looked into how NR affected EU countries' environmental quality using PMG methodologies.	1996–2014	PMG techniques	It was determined that the decline in environmental quality in EU countries was caused by the availability of NR.	Develop policies to mitigate the environmental impact of natural resource extraction and promote sustainable development in EU countries.
Bekun, Alola, et al. (2019b)	16 EU economies	Consider the interplay of several factors with respect to resource rent and carbon emissions.	1996–2014	Panel Pooled Mean Group-ARDL model	Eventually, a positive correlation between NRR and CO_2 emissions was established.	Implement measures for proper management and conservation of NR to mitigate CO_2 emissions.
A. Ullah et al. (2021a)	Top 15 RE economies	Analyze the nonlinear relationship between NRR and environmental impact.	1996–2018	Panel Smooth Transition Model	There is a positive and statistically significant relationship between NRR and environmental impacts in low- and high-income countries.	Develop policies aimed at sustainable utilization of NR to mitigate environmental degradation.

Tufail et al. (2021)	OECD economies	Analyze how fiscal decentralization and NR can help reduce CO_2 emissions.	1990–2018	ARDL models	Rent from NR helps the environment by cutting down on CO_2 emissions. .	Implement policies to promote sustainable resource management and fiscal decentralization to address CO_2 emissions.
Joshua & Bekun (2020a)	South Africa	Consider the impact of energy use and NRR on CO_2 emissions.	1970–2017	ARDL and VECM models	In South Africa, there is a long-term correlation between pollutant emissions and overall NRR.	Develop strategies for sustainable energy consumption and management of NR to mitigate CO_2 emissions.
Anh Tu et al. (2021)	China	Investigate the association between national NRR and carbon emission in China.	1995–2017	Panel data analysis	National NRR positively linked with CO_2 emission in China.	Develop strategies to mitigate CO_2 emissions and promote sustainable utilization of NR in China.
A. Ullah et al. (2021b)	Top 15 RE economies	Identify the interrelationship between RE consumption, NRR, CO_2 emission, and	1996–2018	Panel Smooth Transition Model	NRR causes an increase in CO_2 emissions and leads to environmental degradation.	Implement policies for sustainable development focusing on reducing CO_2

		environment quality.				emissions and conserving natural resources.
Ulucak et al. (2020a)	OECD countries	Examine the OECD nations' energy consumption patterns in connection to their economic development, natural resource use, and environmental sustainability.	1980–2016	AMG estimator	Increasing extraction of NR leads to growing CO_2 emissions in OECD countries.	Implement policies to promote sustainable resource management and reduce CO_2 emissions in OECD countries.
A. Khan et al. (2020)	51 BRI countries	Figure out how NR affected the energy-growth-environment degradation nexus in BRI nations.	1990–2016	GMM method	NR positively affects tourism, energy consumption, and CO_2 emissions but have an adverse effect on economic growth in BRI countries.	Implement measures to mitigate adverse environmental impacts while harnessing the potential benefits of NR for sustainable development in BRI countries.
Bekun, Alola, et al. (2019a)	EU-16 states	Integrate natural resource rent in the CO_2 emissions	1996–2014	Kao cointegration test	Natural resource rent significantly contributes to	Develop policies aimed at managing natural resource extraction and

		equation and investigate its impact on CO_2 emission in EU-16 states.			CO_2 emissions in EU-16 states in the long run.	promoting RE sources to reduce CO_2 emissions in EU-16 states.
Danish, Baloch, Mahmood, et al. (2019a)	BRICS countries	Research the effect of BRICS nations' NR endowments on their CO_2 emissions.	1990–2015	AMG panel algorithm	Natural resource endowment contributes to pollution in South Africa but mitigates CO_2 emissions in Russia, with varied impacts observed in Brazil, China, and India.	Tailor policies to the specific contexts of each BRICS country, considering the varied impacts of NR on CO_2 emission.
H. Liu et al. (2022)	Latin American countries	Find out how Latin American countries' education systems, NR endowments, and CO_2 emissions are correlated, both linearly and non-linearly.	1990–2020	Second-generation advanced econometric methods	U-shaped relationship between NR and CO_2 emissions was observed in Latin American countries, with lower levels of NR beneficial for the environment.	Develop strategies to manage natural resource use in Latin American countries to minimize environmental degradation and CO_2 emissions.

W. Azam et al. (2023b)	France	Make use of the EKC framework to analyze how NR, alternative energy, and public expenditure affect France's environmental sustainability.	1990–2018	FMOLS and GLM	In France, there is a negative relationship between CO_2 emissions, NR, alternative and nuclear energy, and public expenditure.	Implement policies to promote alternative energy sources, reduce reliance on NR, and increase government spending on environmental sustainability measures in France.
Amarpuri et al. (n.d.)	India	Make use of a CNN-LSTM deep learning hybrid approach to forecast India's CO_2 emissions.	2005-2020	CNN–LSTM model	The CNN–LSTM model accurately predicts CO_2 emissions trends in India.	Develop policies and strategies to mitigate CO_2 emissions in India and promote the adoption of clean energy technologies to achieve sustainability goals effectively.

CHAPTER 3

Methodology

3. Data Description and Model Specification

3.1. Data description

This study uses yearly data from the World Development Indicators Database for the High CO_2 Emissions Economies (China, USA, India, Russia, Brazil) and the Low CO_2 Emissions Economies (Sweden, Norway, New Zealand, Costa Rica, Switzerland). Databases were chosen from the period beginning in 1990 and ending in 2020. For consistent and reliable analysis, the data on designated variables were transformed into natural logs. These variables include CO_2 emissions (metric tonnes per capita), GDP per capita (current US$), renewable energy consumption (% of total final energy consumption), fossil fuel energy consumption (% of total), patent application (total patent, residents), total natural resources rents (% of GDP), and government effectiveness (estimate GE.EST). Within the empirical study, the natural logarithms of CO_2 emissions, GDP per capita, and patent applications are denoted as CO_2, GDP per capita, and PTS, respectively. In Table 1 you may find all the data in a concise format.

Table 2. Summary dataset variables

Symbol	Variables	Description	Source
CO_2	CO_2 emissions	metric tons per capita	World Development Indicators
REC	Renewable energy consumption	% Of total final energy consumption	World Development Indicators

FF	Fossil fuel energy consumption	(% of total)	World Development Indicators
GDP	GDP (gross domestic product) per capita	(Current US$)	World Development Indicators
PTS	Patent Application,	Total patent, Residents	World Intellectual Property Organization (WIPO)
NRR	Total natural resources rents	(% of GDP)	World Development Indicators
GE.EST	Government Effectiveness	(Estimate GE.EST)	World Development Indicators

Descriptive statistics

The results of the descriptive statistics for each indicator used in the current study are also displayed in Table 3. The univariate analysis used in descriptive statistics displays each of the characteristics of the indicators. The number of observations for all indicators is given as 155. Table 2 also presents the mean values, which are the indicators' average values, the maximum, standard deviation, and minimum values of all indicators are presented.

Table 3: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
HIGH CO_2					
CO_2	155	2959905	2734033	197897	1.09E+07

GDP	155	12214.86	16900	301.501	65120.39
RE	155	23.88813	18.2917	3.18	52.95
FF	155	76.48128	14.0714	51.2158	94.06131
PTS	155	119717.4	258218	1147	1393815
GE	155	0.1692284	0.76389	-0.8115	1.835353
NRR	155	4.591036	4.77349	0.23437	21.5027
LOW CO_2					
CO_2	155	32802.27	15468.2	2871.2	63647.4
GDP	155	39750.23	26671.4	1808.5	102913.5
RE	155	36.87548	13.8674	16.69	61.37
FF	155	52.37494	11.3891	25.1171	72.05136
PTS	155	1466.735	1069.36	8	4224
GE	155	1.549382	0.64703	0.03096	2.168774
NRR	155	2.262902	2.94709	0.00803	12.61767

3.2. Model specification

This paper investigates the links between *GDP per capita, RE, FF, PTS, GE, NRR, and* CO_2 emissions to establish whether the trends observed in the existing literature hold for countries with Economies with High CO_2 Emissions and Low CO_2 Emissions. Accordingly, we formulate an econometric model based on the empirical EKC model, adapted specifically to the selected countries under study. The EKC postulates that as economies develop, environmental degradation initially increases until a certain level of per capita income is reached, beyond which it begins to decline. Following existing literature, this study extends this concept by incorporating additional variables, in particular, natural resources and government effectiveness to provide a more comprehensive view of the factors influencing environmental outcomes. Thus, the econometric model is as follows:

$$CO2_{it} = \alpha + \beta GDP_{it} + \beta RE_{it} + \beta FF_{it} + \gamma PTS_{it} + \delta C_{it} + \mu_{it} \qquad (1)$$

Where CO_2 is the CO_2 emission, GDP per capita represents Gross Domestic Product per capita., RE represents renewable energy, FF represents fossil fuel, and PTS represents patent application. C represents all the control variables presented in the present model and these are natural resources rent (NRR), and government effectiveness (GE). α is the parameter of the y-intercept. μ_{it} is the white noise term. β, γ and δ are the coefficient parameters of the independent variables. For this reason, we present the research statistical model in Equation 2.

$$\ln CO2_{it} = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} RE_{it} + \beta_{3it} FF_{it} + \beta_{4it} lnPTS_{it} + \beta_{5it} NRR_{it} + \beta_{6it} GE_{it} + \mu_{it} \qquad (2)$$

In Equation 2, α_0 is the y-intercept parameter. μ_{it} is the white noise error term of the statistical model. β_{1it} to β_{4it} are the coefficient parameters of the explanatory variables. *ln* represents the log form of an indicator.

Model 1 for high CO_2 economies

$$\ln CO2_{it} = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} RE_{it} + \beta_{3it} lnPTS_{it} + \beta_{4it} NRR_{it} + \beta_{5it} GE_{it} + \mu_{it} \qquad (3)$$

Model 2 for high CO_2 economies

$$\ln CO2_{it} = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} FF_{it} + \beta_{3it} lnPTS_{it} + \beta_{4it} NRR_{it} + \beta_{5it} GE_{it} + \mu_{it} \qquad (4)$$

We separated the overall model into models 1 and 2 for high CO_2 emission countries because there is multicollinearity between RE and FF. So, in model 1, we put RE, and in model 2 FF separately

Model 1 for low CO_2 economies

$$\ln C02_{it} = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} RE_{it} + \beta_{3it} FF_{it} + \beta_{4it} lnPTS_{it} + \beta_{5it} NRR_{it} + \mu_{it} \qquad (5)$$

Model 2 for low CO_2 economies

$$\ln C02_{it} = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} RE_{it} + \beta_{3it} FF_{it} + \beta_{4it} NRR_{it} + \beta_{5it} GE_{it} + \mu_{it} \qquad (6)$$

We separated the overall model into models 1 and 2 for high CO_2 emission countries because there is multicollinearity between log PTS and GE. So, in model 1, we put log PTS, and in model 2 GE separately

3.4. Method of the study

This research follows the three major stages of data analysis.

Stage 1: Preliminary test on panel variables.

The initial stage of an econometric study to guarantee reliable estimates is to ascertain if the series is stationary. Panel unit root tests are categorized as either second-generation or first-generation tests when they are used to analyze panel data. Each test's reliability depends on whether or not the panel's nations are cross-sectionally dependent. (J. Wang & Dong, 2019). state that first-generation stationarity tests do not consider cross-sectional dependence, hence second-generation tests are more appropriate after confirming the presence of cross-sectional dependence across nations. Thus, the second-generation panel unit root tests—CADF and CIPS—that were established (Pesaran, 2007) are utilized in this investigation. These tests assume cross-sectional dependence and homogeneity (Danish & Wang, 2019; Kouton, 2019)

Stage 2: Preliminary test on the research model

During the research process in this research article, the multi-collinearity test, co-integration test, heterogeneity, and inefficiency of the weak CD tests were conducted to identify the appropriate data analysis method. The VIF method is leveraged for this purpose to check multi-collinearity problems. This helps in preventing co-linearity that would result when two highly correlated independent variables are specified together in the model. In the model, two techniques are applied to check whether it is a test of cointegration among the variables. It helps to verify if they have any long-term relationship. This method can be understood as the Pedroni, Kao, and Westerlund methods. Cross-sectional means are subtracted when testing cointegration in the model, through a process called demean, to provide robust results in the presence of CD. The heterogeneity is assessed by utilizing the slope heterogeneity test developed by (Hashem Pesaran & Yamagata, 2008) The presence of weak CD is assessed using the scaled Lagrange Multiplier (LM) methods proposed by (Frees, 1995), (Friedman, 1937), and (Pesaran, 2015). The preliminary tests in the model are fundamental in choosing the best model for analyzing the association presented in the model.

Stage 3: MMQR method

This research uses the MMQR with fixed effects of (Machado & Santos Silva, 2019) to examine the relationship presented in the present model. The MMQR is the SG method, that gives long-run results and overcomes heterogeneity and weak CD in the model. It is also a dynamic method and a contemporary method that presents robust results. It presents heterogeneous results in different quantiles, allowing for analysis of the asymmetric effects on the dependent variable. Recent studies have recommended the use MMQR method because of its efficiency in presenting sound results, (Z. Khan et al., 2023; Y. Zhang et al., 2023)

MMQR presents that the conditional quantile explained factor is $Q_y(\delta ! X'it)$ and is represented in equation 7(Lv et al., 2024)

$$Y_{it} = \alpha_i + X_{it}\emptyset + (ƛi + Z'it\psi)\mathrm{U}_{it} \qquad (7)$$

Eq 7, the probability is indicated by $(ƛi + Z'it\psi > 0)$ but less than or equal to 1. $(\acute{\alpha},\ \emptyset and \psi)$ are the estimated parameters. ($\acute{\alpha}$i, and ƛi), 1 …. n, denotes the specific fixed effects. Therefore, the statistical MMQR model to be estimated in this research is presented in Equation 8

$$Q_y(\delta ! X'it) = \mathrm{X}_{it} + \varphi\ Z_{it}\Psi q(\delta) + (\alpha^{\cdot} i + \lambda iq(\delta)) \qquad (8)$$

Thus, Equation 8 is the MMQR statistical version of Equation 1 to be estimated in this Chapter.

The estimated models in Table 10 are specified as Model 1 and 2 for high CO_2 economies (9,10), Model 1 for low CO_2 economies (11,12)

$$Q_{\ln CO2_{it}}(\delta! X'it) = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} RE_{it} + \beta_{3it} lnPTS_{it} + \beta_{4it} NRR_{it} + \beta_{5it} GE_{it} + \mu_{it} \quad (9)$$

$$Q_{lnCO2_{it}}(\delta! X'it) = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} FF_{it} + \beta_{3it} lnPTS_{it} + \beta_{4it} NRR_{it} + \beta_{5it} GE_{it} + \mu_{it} \quad (10)$$

$$Q_{lnCO2_{it}}(\delta! X'it) = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} RE_{it} + \beta_{3it} FF_{it} + \beta_{4it} lnPTS_{it} + \beta_{5it} NRR_{it} + \mu_{it} \quad (11)$$

$$Q_{lnCO2_{it}}(\delta! X'it) = \alpha_0 + \beta_{1it} lnGDP_{it} + \beta_{2it} RE_{it} + \beta_{3it} FF_{it} + \beta_{4it} NRR_{it} + \beta_{5it} GE_{it} + \mu_{it} \quad (12)$$

CHAPTER 4

Results and Discussions

4. Empirical Result and Discussion

This research employs the CD test of Pesaran (2004) to examine if the panel indicators of the present research model exhibit significant CD issues. The CD test outcomes presented in Table 4 depict that the Emerging Economies with High CO_2 Emissions for a log of GDP per capita, FF, PTS, GE., and NRR, have significant CD. However, RE and log CO_2 do not have significant unit roots. In the Low CO_2 log of GDP per capita, RE, FF, log PTS, and NRR have significant CD while log CO_2 and GE do not have significant unit roots. Therefore, some variables have CD issues while a few others do not have significant CD issues. Since most of the indicators exhibit significant CD issues, it is imperative to use the SG (second generation) techniques to check unit root

Table 4: Panel CD test

	Statistic	p-value	Statistic	p-value
	HIGH CO_2		**LOW CO_2**	
log CO_2	0.87	0.382	0.51	0.607
logGDP	15.75	0.000	16.50	0.000
RE	1.00	0.316	2.44	0.015
FF	-3.19	0.001	3.27	0.001
logPTS	12.55	0.000	6.23	0.000
GE	-2.63	0.008	0.11	0.912
NRR	10.42	0.000	2.76	0.006

The SG unit root methods of checking unit root, that is, the CIPS and CADF are employed and their findings are presented in Table 5. The CIPS outcomes depict that Log CO_2, RE, and GE have no unit root at the level. However, the CIPS method results depict that log GDP per capita, FF, log PTS, and NRR have unit root at level, but no unit root at first difference. The CADF method concurs with the findings of the CIPS method that LOG CO_2 has no unit root at the level. Additionally, the results of CADF method supports the findings of the CIPS method in providing that log GDP per capita, RE, FF, log PTS, GE, and NRR have unit roots at level, but no unit roots at first difference. This discrepancy suggests that while log CO_2 is not stationary in levels according to the CIPS test, it becomes stationary in first differences according to the CADF test.

In the data set for low CO_2, log GDP per capita, FF, GE, and NRR have no unit root at levels, however, the CIPS method results depict that log CO_2, FF, log PTS, and NRR have unit root at level, but no unit root at first difference. The CADF method concurs with the findings of the CIPS method that log GDP per capita has no unit root at the level. Additionally, the results of CADF method supports the findings of the CIPS method in providing that log CO_2, RE, FF, log PTS, GE, and NRR have unit roots at level, but no unit roots at first difference. This discrepancy suggests that while log GDP per capita is not stationary in levels according to the CIPS test, it becomes stationary in first differences according to the CADF test.

Table 5: Unit root results

	CIPS		**CADF**	
	Level	1st Difference	Level	1st Difference
HIGH CO_2				
***log* CO_2**	-2.463**		-3.052***	
logGDP	-1.698	-3.984***	-2.048	-2.654**

RE	-2.708***		-2.152	-2.490**
FF	-1.510	-4.761***	-1.365	-2.719***
logPTS	-2.257*	-5.725***	-2.468*	-3.080***
GE	-3.153***		-2.12	-2.800***
NRR	-2.160	-5.566***	-1.377	-2.982***
LOW CO_2				
log **CO_2**	-1.477	-6.004***	-1.079	-3.355***
log GDP	-2.667***		-2.950***	
RE	-1.998	-5.622***	-1.835	-2.754**
FF	-2.570***		-2.274*	-3.500***
logPTS	-1.703	-4.951***	-1.054	-2.630**
GE	-2.563***		-1.787	-3.438***
NRR	-2.552***		-1.736	-2.928***

*** is 1% significant; ** 5% significant; * 10% significant

To test multi-collinearity in the research model specified, the Variance Inflation Factors (VIF) method is used to assess multicollinearity among predictor variables in our models. Multicollinearity occurs when predictor variables in a regression model are highly correlated, which can lead to issues with model stability. VIF measures the extent to which the variance of an estimated regression coefficient is inflated due to multicollinearity. The results of the VIF method presented in Table 6 depict categorized by levels of CO_2 emissions (HIGH CO_2 and LOW CO_2) and across different models (Overall, Model 1, and Model 2).

For the high CO_2 category, the variables RE and FF exhibit high VIF values above 10, thus, they are strongly correlated. However, In Models 1 and 2, their VIF value is less than 10, meaning that there is no multi-collinearity anymore i.e. After separating and specifying them in a separate model 1 and 2 to avoid multicollinearity between them. Conversely, the variables log PTS, log GDP per capita, GE, and NRR show comparatively lower VIF values, suggesting less multicollinearity in the high CO_2 category.

In the low CO_2 category, the variable GE and log PTS exhibit high VIF values above 10, thus, they are strongly correlated. However, In Models 1 and 2, their VIF value is less than 10, meaning that there is no multi-collinearity anymore. Variables such as RE, FF, log PTS, log GDP per capita, and NRR demonstrate lower VIF values in the low CO_2 category.

Overall, while some variables exhibit multicollinearity issues, others appear to have less correlation with other predictors, suggesting more stable relationships in the regression models. This interpretation is crucial for understanding the reliability of the regression analyses and making appropriate adjustments to improve model validity.

Table 6: VIF results

Variable	*VIF*	*1/VIF*	*VIF*	*1/VIF*	*VIF*	*1/VIF*
	Overall		Model 1		Model 2	
			HIGH CO_2			
RE	47.97	0.020846*	6.51	0.153693		
FF	47.81	0.020916*			6.48	0.154211

logPTS	9.49	0.105422	4.58	0.218573	7.32	0.136558
logGDP	8.33	0.120024	2.68	0.373480	3.22	0.310817
GE	4.79	0.208736	4.53	0.220746	4.27	0.234100
NRR	4.18	0.239171	4.15	0.240882	3.68	0.271870
Mean VIF	20.43		4.49		4.99	
LOW CO_2						
RE	4.42	0.226091	4.42	0.226104	4.42	0.226180
FF	2.36	0.424192	2.32	0.430339	2.34	0.426585
logPTS	17.40	0.057461*	2.73	0.365693		
logGDP	4.47	0.223787	3.04	0.328416	4.16	0.24041
GE	24.19	0.041345*			3.80	0.263124
NRR	4.99	0.200426	4.94	0.202228	4.91	0.203718
Mean VIF	9.64		3.49		3.93	

Cointegration in this research is checked by employing the tests using different methods (Westerlund, Kao, and Pedroni) to examine the relationship between variables, particularly focusing on the variables "HIGH CO_2" and "LOW CO_2". The cross-section means in the panel variables are subtracted using the demean method to assess the long-term equilibrium relationship between non-stationary variables.

In the set of High CO_2 for Westerlund (2007) Method both Model 1 and Model 2, the p-values for the test statistics Gt, Ga, Pt, and Pa are consistently high. This suggests that there is no evidence to reject the null hypothesis of no cointegration between the variables at conventional significance levels. For the Kao Method in Model 1, the p-value for the Modified DF statistic is 0.0992, which is close to the conventional significance level of 0.05. This suggests weak evidence against the null hypothesis of no cointegration. Other statistics and p-values do not show significant evidence against the null hypothesis. For the Pedroni Method, In Model 1, the p-value for the Modified PP statistic is 0.0452, which is below the conventional significance level of 0.05. This suggests strong evidence against the null hypothesis of no cointegration. In model 2 Modified PP statistic is 0.0787 which is close to the conventional significance level of 0.05. This suggests weak evidence against the null hypothesis of no cointegration. Other statistics and p-values do not show significant evidence against the null hypothesis.

In Low CO_2, for Westerlund's (2007) Method both Model 1 and Model 2, the p-values for the test statistics Gt, Ga, Pt, and Pa are consistently high. This suggests that there is no evidence to reject the null hypothesis of no cointegration between the variables at conventional significance levels. For Kao Method in Model 1, the p-value for the Unadjusted Modified DF and Unadjusted DF statistic is (0.0027 and 0.0147) which is below the conventional significance level of 0.05. This suggests strong evidence against the null hypothesis of no cointegration while the DF statistic is 0.0820 which is close to the conventional significance level of 0.05. This suggests weak evidence against the null hypothesis of no cointegration while for Model 2 Unadjusted Modified DF and Unadjusted DF statistic is (0.0060 and 0.0220) which is below the conventional significance level of 0.05. This suggests strong evidence against the null hypothesis of no cointegration. Other statistics and p-values do not show significant evidence against the null hypothesis. For the Pedroni Method, In Model 1, the p-value for the PP and ADF statistic is (0.0049 and 0.0013), which is below the conventional significance level of 0.05. This suggests strong evidence against the null hypothesis of no cointegration while in Model 2 Modified PP p-value is 0.0280 which is also below the conventional significance level of 0.05. This suggests strong evidence against the null hypothesis of no cointegration. Other statistics and p-values do not show significant evidence against the null hypothesis.

The cointegration results in Table 7 depict the results from different cointegration methods suggesting varying degrees of evidence regarding the presence of cointegration between the variables, with some methods indicating weak evidence and others suggesting stronger evidence against the null hypothesis of no cointegration. Thus, it is fundamental to examine the association presented in the present model by using methods that present long-run results.

Table 7: Cointegration results

Westerlund (2007) method						
Statistic	Value	z-value	P-value	Value	z-value	P-value
	Model 1			***Model 2***		
	HIGH CO_2					
Gt	-0.229	5.672	1.000	-1.878	1.802	0.964
Ga	-2.097	3.493	1.000	2.874	3.283	1.000
Pt	-3.788	1.404	0.920	-3.921	1.281	0.900
Pa	-5.456	1.572	0.942	-4.679	1.781	0.963
	LOW CO_2					
Gt	-1.597	2.463	0.993	-1.278	3.210	0.999
Ga	-2.547	3.371	1.000	-2.217	3.461	1.000
Pt	-4.557	0.693	0.756	-3.680	1.505	0.934
Pa	-2.174	2.453	0.993	-3.187	2.181	0.985
Kao Method						
		Statistic	p-value		Statistic	p-value
	HIGH CO_2					
		Model 1			***Model 2***	
Modified DF		1.2862	0.0992*		0.9566	0.1694
DF		-0.3503	0.3631		-0.4786	0.3161
ADF		0.2539	0.3998		0.2529	0.4002
Unadjusted modified DF		0.4358	0.3315		-0.0638	0.4746
Unadjusted DF		0.1022	0.4593		0.0291	0.4884
	LOW CO_2					
Modified DF		-1.0769	0.140		-0.8087	0.2093
DF		-1.3921	0.0820*		-1.1710	0.1208
ADF		-0.9407	0.1734		-1.0910	0.1376
Unadjusted modified DF		-2.7808	0.0027*		-2.5113	0.0060*

Unadjusted DF	-2.1787	0.0147*		-2.0137	0.0220*
Pedroni Method					
	HIGH CO_2				
Modified PP	1.6938	0.0452*		1.4138	0.0787*
PP	-0.4771	0.3166		-1.2328	0.1088
ADF	-0.1674	0.4335		0.8897	0.1868
	LOW CO_2				
Modified PP	0.5233	0.3004		1.9108	0.0280*
PP	-2.5814	0.0049*		0.4307	0.3333
ADF	-3.0031	0.0013*		-0.3076	0.3792

Heterogeneity in this research is also tested by employing the slope heterogeneity test proposed by (Hashem Pesaran & Yamagata, 2008). The results of the slope heterogeneity test are presented in Table 8, Two different model specifications, Model 1 and Model 2, in high and low CO_2 were analyzed. Both Model 1 and Model 2 yielded statistically significant results ($p < 0.001$) for the tests of heterogeneity involving the variables HIGH CO_2 and LOW CO_2. The Δ and Δ adj. statistics indicate significant heterogeneity in the relationships involving both HIGH CO_2 and LOW CO_2 across different contexts. Therefore, methods that overcome heterogeneity in the analysis are employed, for robust outcomes

Table 8: Heterogeneity results

	Statistics	*p-value*	*Statistics*	*p-value*
	Model 1		Model 2	
	HIGH CO_2			
Δ	10.510	0.000	9.617	0.000
Δ adj.	11.945	0.000	10.929	0.000
	LOW CO_2			
Δ	8.259	0.000	6.712	0.000
Δ adj.	9.386	0.000	7.628	0.000

This study also checks for weak CD (cross-sectional dependence). in the research model by using the three methods, that is the (Pesaran, 2015) scaled LM, (Frees, 1995), and the (Friedman, 1937) methods for both HIGH CO_2 and LOW CO_2.

The weak CD results presented in Table 9 depict high CO_2 in both Model 1 and 2, The Pesaran method test statistic is (-0.545 and -1.866) with a p-value of (0.58 and 0.06) suggesting weak evidence against the Weak CD hypothesis but not statistically significant at conventional levels even if model 2 is slightly stronger. The Friedman method test statistic is (31.78 and 14.64, respectively) with p-values of (0.0000 and 0.0055) providing strong evidence against the Weak CD hypothesis, indicating significant evidence against weak CD although slightly weaker than in Model 2. The Frees method test statistic is (0.80 and 0.69, respectively) with p-values of 0.0000, indicating strong evidence against the Weak CD hypothesis.

In low CO_2 in both Model 1 and 2, The Pesaran method test statistic is (1.139 and 1.265) with a p-value of (0.25 and 0.20) suggesting weak evidence against the Weak CD hypothesis but not statistically significant at conventional levels. The Friedman method test statistic is (33.17 and 33.87, respectively) with p-values of 0.0000 providing strong evidence against the Weak CD hypothesis, indicating significant evidence against weak CD. The Frees method test statistic is (0.38 and 0.45, respectively) with p-values of 0.0000, indicating strong evidence against the Weak CD hypothesis.

These results suggest that in the "HIGH CO_2" scenario, there is generally weaker evidence against the Weak CD hypothesis compared to the "LOW CO_2" scenario, especially in Model 2. However, significant evidence against the Weak CD hypothesis is observed in both scenarios and models, particularly with the Friedman and Frees tests.

Table 9: Weak CD results

Test method	Statistics	p-value	Statistics	p-value
	Model 1		Model 2	
	HIGH CO_2			
Pesaran (2015)	-0.545	0.5855	-1.866	0.0620
Friedman (1937)	31.785	0.0000	14.647	0.0055
Frees (1995, 2004)	0.802	0.0000	0.692	0.0000
	LOW CO_2			
Pesaran (2015)	1.139	0.2547	1.265	0.2058
Friedman (1937)	33.174	0.0000	33.871	0.0000
Frees (1995, 2004)	0.388	0,0000	0.459	0.0000

The MMQR method that presents heterogeneous results across quantiles is used in the research (Machado & Santos Silva, 2019). This table appears to present the results of a quantile regression analysis with different quantile levels (0.1, 0.25, 0.5, 0.75, and 0.9) for two models (Model 1 and Model 2) under different conditions (HIGH CO_2 and LOW CO_2). Each row corresponds to a specific quantile level, and each column provides coefficients, z-statistics, and p-values for various predictor variables. The interpretation would typically involve understanding how each predictor variable (log GDP per capita, log PTS, RE, GE, NRR, FF) contributes to the dependent variable, CO_2 emissions.

Firstly, In the set of high CO_2s for model 1, if log GDP per capita increases by 1%, the dependent variable CO_2 emission increases by 0.082, 0.112, 0.136, and 0.157, for quantiles 0.25 to 0.9 respectively. However, for quantile 0.1 the effect of GDP per capita on CO_2 emission is insignificant. This shows that there are asymmetric effects. If log PTS increases by 1%, the dependent variable CO_2 increases by 0.121, 0.122, 0.122, 0.123, and 0.123, For quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of log PTS on CO_2 is significant. If RE increases by 1 % the dependent variable CO_2 emission increases by -0.043, -0.042, -0.040, -0.038, and -0.037, For quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of RE on CO_2. is significant. If GE increases by 1 % the dependent variable CO_2 increases by -0.292, -0.308, -0.337, -0.359, -0.379, For quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of GE on CO_2 is significant. If NRR increases by 1 % the dependent variable CO_2 increases by -0.007 For quantiles 0.5 respectively. However, for quantiles 0.1,0.25,0.75,0.9 the effect of NRR on CO_2 is insignificant. This shows that there are asymmetric effects

Secondly in model 2 for high CO_2, if log GDP per capita increases by 1%, the dependent variable CO_2 emission increases by 0.099, 0.130, 0.153, and 0.168 for quantiles 0.25 to 0.9 respectively. However, for quantile 0.1 the effect of GDP per capita on CO_2 is insignificant. This shows that there are asymmetric effects. If log PTS increases by 1%, the dependent variable CO_2 increases by 0.120, 0.116, 0.108, 0.102, and 0.099 for quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of log PTS on CO_2 is significant. If GE increases by 1 % the dependent variable CO_2 increases by -0.272, -0.263, -0.246, -0.234, -0.225, for quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of GE on CO_2 is significant. If FF increases by 1 % the dependent variable CO_2 emissions. increases by 0.049, 0.048, 0.046, 0.045, and 0.044 for quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of FF on CO_2 is significant. for NRR all quantiles are insignificant to the dependent variable CO_2 emission.

Table 10: MMQR results

	Coefficient	*z-statistics*	*p-value*	*Coefficient*	*z-statistics*	*p-value*
	HIGH CO_2			**LOW CO_2**		
	Model 1					
	0.1 Quantile					
logGDP	0.0656782	1.60	0.109	0.2352052	6.09	0.000*
logPTS	0.1217071	3.29	0.001*	0.0462141	0.71	0.477
RE	-0.0437694	-8.76	0.000*	-0.033860	-7.35	0.000*
GE	-0.2923549	-2.88	0.004*			
NRR	-0.0000704	-0.01	0.989	-0.022679	-2.45	0.014*
FF				-0.012827	-2.73	0.006*
	0.25 Quantile					
logGDP	0.0822722	2.64	0.008*	0.2246345	8.46	0.000*
logPTS	0.1221102	4.4	0.000*	0.0654378	1.46	0.000*
RE	-0.0426336	-11.32	0.000*	-0.031677	-10.01	0.143
GE	-0.3081037	-4.04	0.000*			
NRR	-0.002533	-0.65	0.517	-0.022342	-3.51	0.000*
FF				-0.01336	-4.14	0.000*
	0.5 Quantile					
logGDP	0.112784	3.31	0.001*	0.214789	10.07	0.000*
logPTS	0.1228515	4.03	0.000*	0.0833426	2.32	0.021*
RE	-0.0405452	-9.81	0.000*	-0.029643	-11.51	0.000*
GE	-0.3370615	-4.02	0.000*			
NRR	-0.0070611	-1.65	0.099*	-0.022029	-4.34	0.000*
FF				-0.013856	-5.38	0.000*

	0.75 Quantile					
logGDP	0.1363548	2.65	0.008*	0.1982857	6.10	0.000*
logPTS	0.1234242	2.65	0.008*	0.1133553	2.07	0.038*
RE	-0.0389318	-6.19	0.000*	-0.026234	-6.78	0.000*
GE	-0.3594317	-2.81	0.005*			
NRR	-0.0105591	-1.63	0.102	-0.021504	-2.76	0.006*
FF				-0.014687	-3.72	0.000*
	0.9 Quantile					
logGDP	0.1575234	2.19	0.028*	0.1896874	4.39	0.000*
logPTS	0.1239385	1.93	0.053*	0.1289919	1.77	0.076*
RE	-0.0374829	-4.31	0.000*	-0.024458	-4.78	0.000*
GE	-0.3795221	-2.15	0.031*			
NRR	-0.0137007	-1.52	0.128	-0.02123	-2.04	0.041*
FF				-0.01512	-2.87	0.004*
	Model 2					
	0.1 Quantile					
logGDP	0.0836001	1.50	0.135	0.2351495	6.20	0.000*
logPTS	0.1202138	2.56	0.010*			
FF	0.0496343	7.40	0.000*	-0.011452	-2.42	0.015*
GE	-0.2728044	-2.06	0.039*	-0.045844	-0.31	0.755
NRR	0.0065171	1.03	0.302	-0.020366	-2.21	0.027*
RE				-0.034265	-6.66	0.000*
	0.25 Quantile					
logGDP	0.0998803	2.33	0.020*	0.2179446	8.08	0.000*
logPTS	0.1161805	3.25	0.001*			
FF	0.0487126	9.54	0.000*	-0.011771	-3.51	0.000*
GE	-0.2638085	-2.62	0.009*	-0.064375	-0.62	0.537
NRR	0.0054528	1.13	0.257	-0.020827	-3.19	0.001*
RE				-0.033154	-9.07	0.000*

	0.5 Quantile					
logGDP	0.1308671	5.18	0.000*	0.1981591	9.27	0.000*
logPTS	0.1085039	5.27	0.000*			
FF	0.0469584	15.92	0.000*	-0.012137	-4.65	0.000*
GE	-0.2466864	-4.27	0.000*	-0.085684	-1.06	0.291
NRR	0.0034269	1.23	0.218	-0.021357	-4.20	0.000*
RE				-0.031876	-11.15	0.000*
	0.75 Quantile					
logGDP	0.1532931	5.44	0.000*	0.1720694	5.57	0.000*
logPTS	0.1029481	4.38	0.000*			
FF	0.0456888	13.62	0.000*	-0.01262	-3.31	0.001*
GE	-0.2342947	-3.55	0.000*	-0.113784	-0.96	0.337
NRR	0.0019607	0.62	0.535	-0.022055	-2.97	0.003*
RE				-0.03019	-7.25	0.000*
	0.9 Quantile					
logGDP	0.1688657	4.43	0.000*	0.1531154	3.51	0.000*
logPTS	0.0990902	3.12	0.002*			
FF	0.0448072	9.86	0.000*	-0.012971	-2.37	0.018*
GE	-0.2256899	-2.52	0.012*	-0.134199	-0.79	0.429
NRR	0.0009426	0.22	0.826	-0.022562	-2.12	0.034*
RE				-0.028966	-4.88	0.000*

*** is 1% significant; ** 5% significant; * 10% significant

Moreover, in the set of Low CO_2 for model 1, If log GDP per capita increases by 1%, the dependent variable CO_2 emission increases by 0.235, 0.224, 0.214, 0.198, and 0.189 for quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of GDP per capita on CO_2 emission is significant. If log PTS increases by 1%, the dependent variable CO_2 emission increases by 0.065, 0.083, 0.113, and 0.128, For quantiles 0.25 to 0.9 respectively. However, for quantile 0.1 the effect of log PTS on CO_2 emission. is insignificant. This shows that there are asymmetric effects. If RE increases by 1 % the dependent variable CO_2 emission increases by -0.033, -0.031, -0.029, -0.026, and -0.024, For quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of RE on CO_2 emission is significant. If NRR increases by 1 % the dependent variable CO_2 emission increases by -0.022, -0.224, -0.022, -0.021, and -0.021, for quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of NRR on CO_2 emission is significant. If FF increases by 1 % the dependent variable CO_2 emission -0.012, -0.013, -0.013, -0.014, and -0.015 For quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of FF on CO_2 emission is significant.

Additionally, in model 2, If log GDP per capita increases by 1%, the dependent variable CO_2 emission increases by 0.235, 0.217, 0.198, 0.172, and 0.153 For quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of log GDP per capita on CO_2 emission is significant. If RE increases by 1 % the dependent variable CO_2 emission increases by -0.034, -0.033, -0.031, -0.030, and -0.028, For quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of RE on CO_2 emission is significant. if NRR increases by 1 % the dependent variable CO_2 emission increases by -0.020, -0.020, -0.021, -0.022, and -0.022 For quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of NRR on CO_2 emission is significant. If FF increases by 1 % the dependent variable CO_2 emission increases -0.011, -0.011, -0.012, -0.012, and -0.012 for quantiles 0.1 to 0.9 respectively. However, for all quantiles the effect of FF on CO_2 emission is significant. For GE all quantiles are insignificant to the dependent variable CO_2 emission.

Based on these research findings on the comprehensive analysis of the factors influencing CO_2 emissions in high and low economies, our finding that GDP per capita has a negative effect on CO_2 emissions in high CO_2 economies supports the EKC hypothesis. Similar results are observed in studies by (Dinda, 2004; Stern, 2004), who argue that economic growth initially leads to higher emissions, but as economies mature, they adopt cleaner technologies that reduce emissions. the panel estimated by (Azam et al., 2016) shows that, from 1971 to 2013, CO_2 emissions and economic growth were significantly correlated negatively in India, but strongly positively in China, Japan, and the

USA. Contrastingly, in low CO_2 economies, the positive effect of GDP per capita on CO_2 emissions aligns with (Narayan & Narayan, 2010) who find that economic growth in these countries still heavily relies on carbon-intensive activities. This suggests that low CO_2 economies need to adopt sustainable development practices early in their growth trajectories to prevent long-term environmental degradation. (Yousefi-Sahzabi et al., 2011) looked into the relationship between Iran's GDP growth and CO_2 emissions. The two factors have a significant and positive relationship, according to the data. (Luzzati & Orsini, 2009) examine the case of SSA countries and find evidence of a positive correlation between GDP per capita and CO_2 emissions, suggesting that economic growth contributes to environmental degradation in these regions. (Jalil & Mahmud, 2009) found evidence of an inverted U-shaped relationship between GDP per capita and CO_2 emissions for a panel of developing countries, (Dogan & Inglesi-Lotz, 2020) using FMOLS and FE methods. The research results show that there is an inverted U-shaped relationship between GDP per capita and CO_2 emissions. (Lean & Smyth, 2010) assert that, at least in the near term, larger increases in GDP will reduce emissions of CO_2. It was also pointed out (Sharma, 2011) that GDP per capita has a positive influence on CO_2 emissions for the global, middle-income, and low-income panels, but no effect at all for the high-income panel, despite the fact that it has a positive effect on CO_2 emissions. The variable GDP per capita has a positive and significant influence on CO_2 emissions in this research, both in the high and low CO_2 emissions. The results of this test are the same as the research conducted by (Fattah et al., 2021). Developing nations' GDP per capita was found to be positively correlated with CO_2 emissions in developing nations of varying economic levels, according to a recent study.(Karthikeyan & Murugesan, 2022) Looking at the data from 1996 to 2021, we can see that GDP per capita reduces the G-7 countries' CO_2 emissions., which means that economic development increases pollution and harms the environment (Pradhan et al., 2024)

In addition, the levels of CO_2 emission showed an improvement for both high and low CO_2 emitting economies Thus, the effect of the adoption of RE sources to CO_2 emission is not a simple one of the complexities noted by (Marques, 2010). From these studies, it can be inferred that the result of the search for sustainable energy increase in the capacity of RE sources does not necessarily mean a decrease in FF use as the total demand for energy rises. This stresses on the importance of sustainable and advanced energy system planning that can successfully incorporate RE into the overall energy mix (H. Khan et al., 2020) including information on 194 countries to assess the relationship between the use of RE and CO_2 emissions. They employed panel analysis to establish that the usage of RE caused a negative impact on CO_2 emissions. For the purpose of comparative analysis, the effect of REN sources on the emissions of CO_2 was reported as the subject of the study performed by (Bilan et al., 2019). Their argument was that we can wean ourselves off of FFs if we replace them with REN sources in our homes and businesses. It reduces the combustion of carbon-based fuels, which are known to release CO_2. Also, (Payne, 2012) looks at how RE, real GDP and CO_2 emissions are related. A review of the laws and regulations pertaining to RE since 1978 reveals that RECs have benefited greatly from these initiatives. Regardless, the results show that RE sources and CO_2 emissions are positively correlated. Autoregressive SVAR analysis was employed by (Silva et al., 2012) to determine the correlation between REC, real GDP, and the CO_2 emission rate. Using RE sources is significantly associated with lower CO_2 emission per capita, according to this study. (Shang et al., 2024) estimated using MMQR methodologies that there is a significant impact of RE sources on carbon emissions across quantiles among the top 10 greatest carbon emitters. Numerous studies have shown that there is a negative relationship between carbon emissions and the use of RE (O. Usman et al., 2017) the use of MMQR fixed effects revealed that the use of RE reduced environmental degradation in the G7 countries. (Mehmood et al., 2023) used CS-ARDL and a wavelet coherence technique to analyze G7 countries from 1990 to 2020 and found a negative correlation between CO_2 emissions and RE consumption. From 1984 to 2007, (Apergis et al., 2010) discovered a positive correlation between carbon emissions and the use of RE in 19 industrialized and developing nations. Nevertheless, they came to the conclusion that using RE sources does not lower carbon emissions based on panel Granger causality testing. Using

ARDL techniques, (Amri, 2017) also found that the consumption of RE had a negligible effect on Algeria's carbon emissions between 1980 and 2011. Similarly, (Saidi & Omri, 2020) used FMOLS and VECM methodologies to analyze 15 large countries that consume a lot of RE and found no long-term correlation between the use of RE and carbon emissions. Using panel Granger causality tests (Saidi & Ben Mbarek, 2016) achieved comparable results for the United States, Canada, France, Japan, Netherlands, Spain, Sweden, Switzerland, and the United Kingdom between 1990 and 2013. (Kongbuamai et al., 2021) found that from 1995 to 2016, the BRICS countries' use of RE reduced environmental degradation through the use of dynamic seemingly unrelated regression (DSUR). Accordingly, the results imply that the relationship between CO_2 emissions and REN use varies according to the methodology applied, the nation's taken into account, and the time periods studied. Similar with the results of the study by (Bölük & Mert, 2014) for the case of the European Union (EU) showed that in no way RE is involved in containing CO_2 emissions. Later, (Bölük & Mert, 2015) investigated Turkey and the relationship found a rather feeble negative correlation between the utilization of RE and carbon emission (Fuinhas et al., 2017) sought to investigate the relationship of RE with emissions for Latin American countries and to establish this, the authors employed the method of panel estimations. They said that the use of RE in these countries would go a long way to help to reduce the level of carbon intensity.

The positive correlation between the usage of FF and CO_2 emissions is confirmed by (Ozturk & Acaravci, 2010; C. Wang et al., 2018). These papers suggest the importance of shifting to cleaner forms of energy to reduce emissions while highlighting the continuing utilization of FFs in various forms in the diverse stages of development. In many areas, this cyclical reliance represents the main reason for policies supporting RE sources, as well as energy efficiency. (Shahbaz & Patel, 2024) MMQR results also show that FF energy has a significantly positive relationship with CO_2 emission for 108 countries where we used annual data from 1990 to 2020 to mitigate the impact of CO_2 emission on global climate change, countries must embrace the use of clean energy and RE. Previous studies by. (Gyamfi & Adebayo,

2023) examined the contribution of FF in the E7 economies over two decades between the years 1990 and 2018. However, their results show that in the case of CO_2, FF have a positive relationship. This section discusses some studies that looked at the correlation between CO_2 emissions and how efficient FF was. This study was aimed at determining the relationship that exists between the availability of fossil energy and that of CO_2 emissions in the 30 provinces in China as established by (Lin & Xu, 2020). Studies used the nonparametric additive regression model and the period from 1990 to 2017 was considered. In the eastern and central regions, where the use of coal and oil shows a more complex pattern depending on the stage of development, the impact of FF volume on CO_2 emissions appears to have a 'U-shape,' which is interesting. However, fossil energy availability has a nonlinear, inverted "U-shaped" effect on CO_2 emissions in the western region due to the cyclical nature of oil and gas extraction and consumption processes. The impact of FF consumption on environmental degradation in Pakistan from 1975 to 2014 was examined in a recent study. (Ali, Gong, et al., 2021). Studies employing the ARDL method uncovered a connection between the variables over the long run, the researchers were able to determine the variables' long-term relationships with one another. Looking at both the long-term and short-term coefficients, they find that the use of FF is directly related to CO_2 emissions. Kartal et al. (2021). pointed out on the relationship between the consumption of FFs and the degradation of the environment in the USA. Using monthly data from the relevant series from January 1989 to September 2021, the article employs nonlinear approaches such as Quantile-on-Quantile Regression, Granger Causality-in-Quantiles, and Wavelet Coherence. Regardless of the time or frequency factor, the results show that energy consumption significantly affects the change in CO_2 emissions in the short, medium, and long terms. In a related empirical study by(Rani et al., 2023) the analysis to establish a relationship between the consumption of fossil energy and emission of CO_2 in the SAARC countries for the period of 1990-2020 was made. The research found that due to the SAARC countries' consumption of FFs, the amount of CO_2 emissions increases with the help of FMOLS, DOLS, and FE-OLS techniques. Analyzing the data from 1972 to 2020, (Yousaf et al., 2022) assessed how the consumption of FFs had impacted the quality of the environment in Pakistan. Short and long-run estimations show that increased FF consumption adversely affects environmental quality as identified by the ARDL technique. (Kartal, 2022)), the author focused on five of the largest emitters to analyze how the consumption of fossil resources impacted the degradation of the environment. Data used in this research were from 1965 to 2019 for the purpose of employing the MARS model. In the case of CO_2 emissions overall, it is thus demonstrated that coal, oil, and natural gas are the most relevant pointers, while other factors vary depending on thresholds. In the context of the African region and for the period of 1980–2014, (Asongu et al., 2020) evaluated that FF consumption is deleterious for the environment. From the ARDL-PMG model, it was established that FF consumption reduces environmental quality. Studies have been conducted on the extent of carbon emission due to the utilization of FFs in Pakistan by (Ali, Zhimin, et al., 2021) The data used in the research was from 1971 to 2014 and the method used was the ARDL method. It was also determined that the causal relationship between FF and CO_2 emissions was unidirectional. In their comprehensive analysis of China's CO_2 emissions from 1980 to 2018, the authors (Abbasi et al., 2022) focused on the correlation between these emissions and the use of FF for energy production. The work included FDC models and used unique dynamic ARDL simulations. In both the short and long run, CO_2 emissions are significantly increased when FF are used as an energy source, according to the research.

The negative effect of natural resource rents on CO_2 emissions in high CO_2 economies supports the findings of (van der Ploeg & Poelhekke, 2009), who suggest that resource-rich countries can leverage their wealth to fund sustainable development projects. On the other hand, the positive effect in the low CO_2 economies is consistent with (Sachs & Warner, 2001), reporting that dependence on NR leads to emissions. This then provides a basis and understanding that these economies need to diversify and more importantly, they should manage their effectively. Furthermore, according to.(Shahbaz & Patel, 2024) the findings relating to the NR rents show a moderating effect on CO_2 emissions, meaning that the emission rate is low in the countries with higher NR rents.in contrast, a limited number of empirical research have focused on the correlation between emissions of CO_2 and NRR. For instance, in this context, (Li et al., 2023) analyzed this relationship in 158 economies and suggested a positive relationship between NRR and CO_2 emissions. (Dechezleprêtre et al., 2023) have considered the same relation in the geographical area like the European Union and a positive linkage has been envisioned in taking position towards NR and carbon emissions. panel corrected standard error (PCSE) results identified by(Li et al., 2024) reveal that there is a significant positive relationship between NR and CO_2 emission in the G-20 countries; the G-20 nations should make efforts towards reducing the exploitation of resources trapped under NR. Similarly,(Liao et al., 2023) synthesized the relationship between these two factors, that is, CO_2 emissions and NR Rent, and pointed out that there was a positive relationship between these two elements.

In this paragraph, we will go over the work of a few scholars who have examined the correlation between NR Rents and CO_2 emissions. (Aladejare, 2022) observed the eleven oil-exporting African countries and related their NR rents to environmental degradation. Data were collected for the sample from 1990 to 2019 to conduct a panel data analysis in the study. Degradation of the environment is a prerequisite of NR rents in the five richest African states. This was proven by (Sicen et al., 2022) when they looked at the relationship between NR rents and CO_2 emissions in the BRICS nations. As a part of the data, the panel data methods were used with the help of data from 1995 to 2018. The total rent on NR has been seen to result in a reduction of carbon emissions that are known to be a cause of global warming. (Adebayo et al., 2022) looked at how technological expansion and the revenues from NR impacted the emittance of CO_2 in ten Newly Industrialized Countries. This study employed the data for the period between 1990 and 2018 and applied the MMQR method. Therefore, this study establishes that environmental deterioration reduces as we go from the first quantile to the last when a combination of technology and NR rent is made. An ecological footprint and NR rent perspective were examined by (Shittu et al., 2021) from 45 Asian countries endowed with natural endowment. The data of the study covers 45 countries for the period of 1990-2018; with different methods of panel data analysis. Based on the findings of the study, ecological footprint hence NR rent is negatively related. (Zhou et al., 2023) examined the nations that are part of the Regional Comprehensive Economic Partnership (RCEP) and how carbon emissions relate to the rent from NR. The study used time series data from 1990 to 2020 and employed the MMQR method. The study's findings confirm that RCEP nations' use of NR rent increases pollution. (Luo et al., 2023) segmented the world's countries according to their GDP to determine how NRR affected the carbon emissions of these nations. Data used in this study was gathered from 1990 to 2018, and the long-term relationships between the variables were determined using a panel cointegration regression test. Upon analyzing the various results, one is able to observe that, in particular if we focus our attention to the countries with low income, there can be observed considerable positive correlation between the values of CO_2 emissions on the one hand and NRR on the other. In a few of the SSACs, (Sibanda et al., 2023)enriched the association between the degradation of the environment and NR rents. The analysis in the current study was conducted using the GMM approach, with data collected in the years from 1994 to 2020. The findings also show a positive relationship between NR rents and environmental degradation through the estimation procedure known as GMM. Their research on environmental degeneration in BRICS nations, as influenced by the NRR was conducted by (Ganda, 2022) This research uncovered further papers that used data from 1990 to 2019 and used three distinct panel data techniques. It was established in the study that the level of NRR was positively related to the level of environmental deterioration. Using the Saudi Arabian case, (Agboola et al., 2021)) evaluated the influence of rent from NR on CO_2 emissions. The cross-sectional analysis was carried out on data collected between the years 1971 to 2016 to establish the long-term relationship that exists between the variables. Results show that the variables are positively correlated over both the long and short term. Research conducted in Vietnam by (Awosusi et al., 2023) examined the connection between environmental sustainability and the rent from NR. The Dynamic ARDL model was employed in this investigation, which covered the years 1984 to 2019. In Vietnam, there is little long-term or short-term impact NR rent on CO_2 emissions. The link between

NR rent and environmental quality in the G7 countries was investigated by (Gyamfi et al., 2022) The research used the QR, AMG, FMOLS, and DOLS methods with data collected between 1990 and 2016. There is a substantial and positive link between the total rent from NR and pollution, according to the empirical findings, with the exception of Q 0.05. A study on the effect of NR rent on ecological footprint was carried out in 90 BRI countries by (Zuo et al., 2021). Information from 1991 to 2018 was used in this study. Using the AMG estimator was the recommended approach. Based on the research, it can be concluded that renting out NR has a detrimental effect on the ecosystem's general health. Research on the effect of NR on CO_2 emissions in 10 recently industrialized nations was conducted by (Bashir et al., 2023) The study discovered that NR increased CO_2 emissions in the countries that were concerned using AMG, CCEMG, and MMQR methods. (Zafar et al., 2021) examined the connection with NR and CO_2 emissions from 1990 to 2018 using data from Asian countries. Researchers found that NR increased CO_2 emissions using second-generation panel estimates. The link between NR and CO_2 emissions from 1995 to 2018 was assessed for MINT nations by (Aziz et al., 2021)). The study identified a favorable role of NR in CO_2 emissions at lower quantiles using the MMQR regression method, but its impact became minor at middle to upper quantiles. (Shah et al., 2023) used AMG and CCEMG panel techniques to evaluate the role of NR in CO_2 emissions from 1990 to 2019. They found that NR decreased CO_2 emissions in ASEAN countries. Also, from 1990 to 2019, Mehmood (2022) calculated the NR and CO_2 emission nexus for four South Asian nations. According to the ARDL Bound testing method, NR had a negative effect on CO_2 emissions in Pakistan and India, a positive effect in Bangladesh, and no effect at all in Sri Lanka.

Patent counts are commonly used to measure the output of innovation activities (Dechezleprêtre et al., 2008; Popp, 2006; Popp et al., 2011a). The positive impact of patent applications on CO_2 emissions in high CO_2 economies is consistent with (Acemoglu et al., 2012), who note that increased innovation and industrial activity can lead to higher emissions if not managed sustainably. In low CO_2 economies, the negative effect of patent applications aligns with (Jaffe et al. 2005), suggesting that technological innovation in these contexts is directed towards more sustainable and efficient practices, thus reducing emissions. According to other studies (Acemoglu et al., 2012; Jaffe et al., 2002), the effect of advances in green technology on CO_2 emissions may change based on a variety of conditions and may also be impacted by time and money. Energy technology patents were found to have very little effect on China's CO_2 emission reduction in research by (Z. Wang et al., 2012) Furthermore, it was discovered that the only area of China where energy patents expressly pertaining to carbon-free technologies reduce CO_2 emissions is the east. According to the research done (Weina et al., 2016) green technologies in Italy improve environmental productivity but have little effect on lowering CO_2 emissions. (Jiao et al., 2020) used the stochastic influences by regression on population, affluence, and technology (STIRPAT) model to show that lowering carbon intensity was significantly impacted by green technology's capacity to spread its advantages to other industries. The study also discovered that the technological spillover's indirect impact outweighed its direct impact. In their research, (Buonanno et al., 2003) showed that countries adhering to the Kyoto Protocol can drastically cut their emission reduction costs through induced technological innovation. (Popp et al., 2011b) found that the most significant impact on energy consumption and carbon emissions was a three-year patent dissemination time based on a study of patent data. The number of trademark applications used in the (M. K. Khan et al., 2019) study as a proxy for technical advancement and innovative output. According to the study's conclusions, innovation lowers CO_2 emissions. Utilizing the ARDL technique, (Shahbaz et al., 2016) investigate how technological progress has affected carbon emissions in Malaysia from the first quarter of 1790 to the fourth quarter of 2011. The researchers find that openness, which is a symbol of technical improvement, leads to economic expansion, which in turn causes carbon emissions to rise.

The positive effect of government effectiveness on CO_2 emissions in high CO_2 economies contrasts with Li and Lin (2015), who find that effective governance usually helps reduce emissions by enforcing environmental regulations. This discrepancy may be explained by the possibility that improved governance in high CO_2 economies also facilitates higher industrial activity, which increases emissions. In low CO_2 economies, the negative effect of government effectiveness on CO_2 emissions aligns with findings by Cagno and Trianni (2014), indicating that effective governance promotes sustainable practices and reduces emissions through stringent environmental regulations. The impact of government effectiveness on CO_2 emissions in 170 countries is examined in the study by (Al-Mulali et al., 2022) utilizing the system GMM technique. This study showed that a significant drop in CO_2 emissions is directly correlated with government operations becoming more efficient. (Danish et al., 2019)looked at the economic activity of five BRICS nations between 1996 and 2017. An improvement in governance quality leads to an improvement in environmental quality, according to the study, which found a negative association between carbon emissions and the composite index of governance quality. The findings also validate that the BRICS countries have an EKC. According to the study done by (A. A. Khan et al., 2022) exports, RE, and good governance all had a negative impact on CO_2 emissions in the G-7 countries between 1990 and 2018. From 2006 to 2019, (Simionescu et al., 2021) studied ten panels of people from Central and Eastern Europe (CEE). The results imply that short- and long-term greenhouse gas emissions are negatively impacted by government effectiveness. (Halkos & Tzeremes, 2013) conducted a study that looked at a number of different countries and found that different amounts of governance quality metrics are relevant in each category, potentially influencing CO_2 emissions. Three measures of governance were studied (Muhammad & Long, 2021) political stability, the rule of law, and corruption control. It was found that these indicators negatively impact carbon emissions. It was demonstrated that there is a positive association between institutional quality and CO_2 emissions, which is consistent with the findings of (M. Usman & Jahanger, 2021), Improvements in political institutional quality contributed to a decrease in CO_2 emissions in South Africa between 1971 and 2017, according to a study by (Sarkodie & Adams, 2018). (X. Zhang et al., 2024)This study primarily looks at the BRICS nations in relation to this issue. The MMQR, Canay (2011) Quantile Regression, and AMG from 1995 to 2021 are used in this study. In keeping with Sustainable Development Goal 16, the study's findings show a consistent relationship between improved government performance and decreased CO_2 emissions. (Sun et al., 2020) conducted an analysis of data from 187 nations between 1996 and 2014 to investigate the relationship between government effectiveness and carbon emissions. A significant relationship between the effectiveness of governance and the decrease in carbon emissions was found by the researchers. A panel data analysis is used by (Oyewo et al., 2024) An analysis of 336 top multinational enterprises (MNEs) is part of the study, which covers a 15-year period from 2006 to 2020. The results show that Government Effectiveness significantly reduces the rate of carbon emissions.

By comparing our findings with these studies, we can conclude that the drivers of CO_2 emissions are multifaceted and vary significantly across different economic contexts. The interplay between economic growth, energy consumption, innovation, and governance is complex, necessitating tailored policy approaches for different countries to effectively mitigate emissions and promote sustainable development.

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CHAPTER 5

Conclusion and Policy Recommendation

Conclusions

The research seeks to examine how GDP per capita, Renewable Energy Adoption, FF Energy Consumption, Patent Application, natural resources, and government effectiveness, affect CO_2 emission in both economies with high CO_2 emissions (China, United States, India, Russia, Brazil) and low CO_2 emission (Sweden, Norway, New Zealand, Costa Rica, Switzerland). This analysis is developed using the MMQR approach for panel fixed effects proposed by (Machado & Silva 2019) for the period from 1990 to 2020 providing a robust longitudinal perspective on these dynamics and capturing the nuanced effects of these variables across different quantiles of CO_2 emissions, offering valuable insights into the dynamics at play in both high and low emission contexts.

This research bridges multiple strands of literature, integrating economic growth theories with environmental sustainability frameworks. It underscores the multifaceted nature of CO_2 emissions drivers, highlighting how economic development, energy consumption patterns, and innovation interplay with institutional factors like government effectiveness and NR management. By incorporating variables such as patent applications and NR rent, the study extends EKC models, providing a more nuanced understanding of emissions trajectories. This theoretical advancement helps in conceptualizing the complex interdependencies and feedback mechanisms that shape environmental outcomes in varying economic settings**.** The research contributes to the growing body of knowledge by offering detailed empirical evidence on the determinants of CO_2 emissions across different economic contexts. For instance, In the MMQR results, in high CO2, log PTS, GE, FF and RE show a positive effect on CO_2 emissions then log GDP per capita and NRR show a negative effect on CO_2 emissions while in low CO_2 log GDP per capita, RE, NRR, FF, shows a positive effect on CO_2 emission, while log PTS and GE shows a negative effect on CO_2 emissions. The use of quantile regression techniques allows for granular analysis of these relationships across different points of the emissions distribution.

The finding that log GDP per capita has a negative effect on CO_2 emissions suggests that as these economies develop, they may be investing in cleaner technologies and more efficient practices, leading to a decoupling of economic growth from emissions. This aligns with the EKC hypothesis, which posits that environmental degradation increases up to a point as a country develops and then begins to decline. Conversely, the positive effect of GDP per capita on CO_2 emissions in low CO_2 economies indicates that economic growth in these countries may still be heavily reliant on carbon-intensive activities. This underscores the need for these countries to adopt sustainable development practices early in their growth trajectories. The positive findings regarding the impact of RE adoption on CO_2 emissions in both high and low CO_2 economies underscore the complexities of transitioning towards a sustainable energy future. While RE adoption is essential for reducing emissions, it is clear that simply increasing RE capacity may not be sufficient to offset the continued reliance on FF. The positive effect of GE on CO_2 emissions in high CO_2 economies suggests that better governance might be facilitating higher industrial and economic activity, which increases emissions. This highlights the complexity of governance where effective administration can simultaneously boost economic growth and emissions. The negative effect of GE on CO_2 emissions in low CO_2 economies indicates that effective governance in these contexts is likely enforcing environmental regulations and promoting sustainable practices, thus reducing emissions. The positive effect of FF consumption on CO_2 emissions in both high and low CO_2 economies is expected and reaffirms the critical need to transition to cleaner energy sources to mitigate emissions. This highlights the continuing dependency on FFs across different stages of economic development. The negative effect of NRR on CO_2 emissions in high CO_2 economies suggests that revenue from NR might be invested in cleaner technologies or more efficient energy use. In contrast, the positive effect in low CO_2 economies could indicate that reliance on extraction is still driving emissions, stressing the need for diversification and sustainable resource management. The positive impact of PTS on CO_2 emissions in high CO_2 economies could imply that increased innovation and industrial activity, while beneficial economically, may also lead to higher emissions if not coupled with sustainable practices. The negative effect in low CO_2 economies suggests that technological innovation in these contexts might be directed towards more sustainable and efficient practices, thus reducing emissions.

The importance of these results lies in their ability to provide nuanced insights into the drivers of CO_2 emissions in different economic contexts. They underscore the need for tailored policy approaches that consider the specific economic, governance, and energy dynamics of high and low CO_2 emission economies. The findings emphasize the complexity of achieving sustainable development and highlight the critical areas for policy intervention to effectively mitigate CO2 emissions while fostering economic growth. This study adds a lot to what is already known about the complicated relationship between innovation, energy consumption, economic growth, and carbon dioxide emissions. By providing a comparative analysis of high and low CO_2 emission economies, the study offers valuable insights into the differentiated impacts of various factors on emissions. These insights are crucial for policymakers, researchers, and practitioners aiming to design effective interventions and strategies for sustainable development. The findings underscore the importance of tailored policy approaches that consider the specific economic, governance, and energy dynamics of different countries, ultimately aiding in the global effort to combat climate change and promote sustainability.

Policy Recommendation

policy recommendations can be tailored to address the unique challenges and opportunities faced by each group of countries. Here are some recommendations Based on the findings.

- It is crucial to invest in cleaner technologies and improve energy efficiency to decouple economic growth from CO_2 emissions. Policies should focus on transitioning to a green economy where economic development does not come at the cost of environmental degradation.

- Enhancing government effectiveness is essential for both high and low-CO_2 economies. Effective governance can enforce environmental regulations, promote sustainable practices, and facilitate the transition to renewable energy sources.
- Policies should aim to improve the efficiency and integration of renewable energy into the existing grid, ensuring that the transition from FFs is both effective and economically viable.
- Innovation should be directed towards sustainable solutions. Governments and policymakers need to incentivize research and development in clean technologies and ensure that patent applications translate into practical, environmentally friendly technologies.
- For both high and low CO_2 economies, the revenue from NR should be strategically invested in sustainable development projects. This can help mitigate the adverse environmental impacts associated with resource extraction and promote economic diversification.

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SIMILARITY RESULT

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APPENDICES

NEAR EAST UNIVERSITY

SCIENTIFIC RESEARCH ETHICS COMMITTEE

23.02.2024

Dear Christiana Chioma Efe-Onakpojeruo

Your application titled **“Comparative Analysis on the Role of Energy Consumption, Technological Progress, Natural Resources, and Government Effectiveness on Carbon Emission for High and Low-emitting Economies.”** with the application number NEU/SS/2024/1775 has been evaluated by the Scientific Research Ethics Committee and granted approval. You can start your research on the condition that you will abide by the information provided in your application form.

Prof. Dr. Aşkın KİRAZ

The Coordinator of the Scientific Research Ethics Committee