THE EFFECT OF ECONOMIC COMPLEXITY ON ENVIRONMENTAL DEGRADATION IN DEVELOPING COUNTRIES: EXAMINING THE MODERATING ROLE OF GREEN ENERGY, GREEN INNOVATION AND INSTITUTIONAL QUALITY

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by

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LIST OF ABBREVIATIONS

CO_2	Carbon dioxide
CC	Control of Corruption
EC	Economic complexity
ECI	Economic complexity index
EG	Electricity grid
ED	Environmental degradation
FDI	Foreign direct investment
GOV	Government Effectiveness
GE	Green energy
GI	Green innovation
GDP	Gross domestic product
INN	Innovation intensity
IQ	Institutional quality
IP	Intellectual property
CH_4	Methane
NRR	natural resources rents

N_2O	Nitrous oxide
POP	Population density
PC	Price controls
RQ	Regulatory Quality
ROL	Rule of Law
TEC	Technology innovation
TRD	Trade
URB	Urban population

KESAN KOMPLEKSITI EKONOMI TERHADAP KEMEROSOTAN ALAM SEKITAR DI NEGARA MEMBANGUN: MENGKAJI PERANAN PENYEDERHANAAN TENAGA HIJAU, INOVASI HIJAU DAN KUALITI INSTITUSI

ABSTRAK

Satu cabaran global utama hari ini adalah perubahan iklim, dengan pemanasan global menjadi ancaman alam sekitar terbesar kepada negara seluruh dunia. Perkembangan yang pesat dalam kerumitan ekonomi mungkin mengeruhkan isu ini, khasnya di negara-negara membangun. Untuk mengatasi korelasi tidak simetri antara kerumitan ekonomi dan kemerosotan alam sekitar, kajian ini menyiasat peranan penengah tenaga hijau, inovasi hijau, dan kualiti institusi ke atas hubungan antara kerumitan ekonomi dan kemerosotan alam sekitar dari 2008 sehingga 2021 di negara-negara membangun. Menggunakan kaedah momen teritlak (GMM), hasil-hasil kajian memberikan petunjuk sokongan, menggambarkan bahawa penggunaan tenaga, inovasi hijau dan kualiti institusi mampu mengekan dengan signifikan kesan negatif kerumitan ekonomi ke atas alam sekitar. Dalam erti kata lain, sekiranya sesebuah negara mampu meningkatkan penggunaan tenaga hijau dan kapasiti inovasi hijau, di samping memperbaiki kualiti institusi, kerumitan ekonomi berkemungkinan bukan sahaja mampu mengelakan dari memburukan kemerosotan alam sekitar, tetapi juga menyumbang dalam peningkatan kualiti alam sekitar. Sebagai sebahagian cadangan polisi, kerajaan patut sepenuhnya menggalakan dan menyokong penggunaan tenaga hijau, yang mana ketika ini rendah khasnya dalam product yang kompleks. Begitu juga, memperkasakan dan meningkatkan inovasi hijau untuk menyokong keluar yang tinggi demi produk kompleks yang ‘hijau’ sesuai dengan

Kesihatan manusia dan alam sekitar patut diintegrasikan juga. Untuk melengkapkan, memperkemaskan kualiti institusi seperti mengembangkan capaian grid, kawalan harga, hak cipta intelek, dan rasuah akan memastikan kecekapan promosi produk kompleks yang mesra alam sekitar.

THE EFFECT OF ECONOMIC COMPLEXITY ON ENVIRONMENTAL DEGRADATION IN DEVELOPING COUNTRIES: EXAMINING THE MODERATING ROLE OF GREEN ENERGY, GREEN INNOVATION AND INSTITUTIONAL QUALITY

ABSTRACT

One of the foremost global challenges today is climate change, with global warming posing the greatest environmental threat to nations worldwide. The rapid advancement of economic complexity may exacerbate this issue, particularly in developing countries. To address the contradictions between economic complexity and environmental degradation, this study investigates the moderating role of green energy, green innovation, and institutional quality in the relationship between economic complexity and environmental degradation from 2008 to 2021 in developing countries. Employing Generalized Method of Moments (GMM), the results provide supportive evidence, showing that green energy consumption green innovation and institutional quality can significantly mitigate the negative impact of economic complexity on the environment, with the quality of institutions playing a crucial role in this moderating effect. In other words, if a country is able to increase the utilization of green energy and enhance innovation capacity while improving institutional quality, economic complexity may not only avoid exacerbating environmental degradation but could also potentially contribute to environmental improvement. As part of the policy suggestions, government should fully encourage and support the use of green energy, which is generally low currently especially among the producers of complex products. In doing so, strengthening and upgrading green innovation to support the higher production of 'green' complex products that

suit to people's health and environment. To complement, streamlining institutional quality, such as expanding grid coverage, pricing control, protecting intellectual property, and controlling corruption can assure the effectiveness of promotion of environmental-friendly complex products.

CHAPTER 1

INTRODUCTION

1.1 Overview

Climate change is one of the most severe environmental challenges confronting the world in the 21st century. It is defined as the alteration of climate patterns, primarily driven by emissions of greenhouse gases (Shahbaz et al., 2019). These emissions trap heat in the Earth's atmosphere, serving as the principal force behind global warming. Research indicates that population growth and increased economic activities have led to a continuous rise in greenhouse gas emissions, imposing significant burdens on various biophysical and ecological systems of the Earth. These changes are impacting the environment globally and disrupting the life-sustaining mechanisms in the atmosphere (You & Lv, 2018). The consequences of climate change include flooding and droughts, extreme rainfall, rising sea levels, temperature increases, and glacial melting. The melting of glaciers has profoundly affected freshwater ecosystems, posing substantial threats to hydropower, agriculture, and human health, thereby impacting human survival (Agovino et al., 2019). However, the adverse environmental exposures are not directly caused by climate change itself, but are instead driven by factors such as carbon emissions, greenhouse gas emissions, the burning of fossil fuels, and the excessive consumption of non-renewable energy sources (Pata, 2021). These factors exacerbate global warming and lead to continuous changes in weather patterns, further intensifying environmental degradation and significantly affecting human health and well-being worldwide (Vu, 2020).

Furthermore, according to the IPCC report, carbon dioxide emissions account for nearly 76% of global greenhouse gas emissions. Human activities and the combustion of fossil fuels emit carbon dioxide. The release of carbon dioxide into the atmosphere is one of the primary causes of climate change and global warming (IPCC, 2013). Over the past three decades, the total global carbon dioxide emissions increased by approximately 63.91% by 2019 (IEA, 2023). Moreover, the COVID-19 crisis forced power plants to maximize the use of coal and other fossil fuels to meet the growing energy consumption demands and to restore economic growth rates to previous levels, resulting in a significant surge in carbon dioxide emissions. This surge is the largest recorded increase in history, with a total exceeding 2 billion tones (Chhabra et al., 2023; IEA, 2023). Consequently, the issue of carbon emissions has become a serious global concern, attracting considerable attention from scientists, environmentalists, policymakers, governments, and national leaders worldwide.

Reducing carbon emissions is one of the key measures to combat climate change. Scientists broadly agree that keeping global carbon dioxide concentrations below 450 parts per million is advisable, as it would help limit the increase in global average temperatures to no more than 1.5 degrees Celsius above pre-industrial levels (Wang, Vo, et al., 2020). Reducing carbon emissions not only helps to slow the pace of global warming but also improves air quality and reduces health issues related to air pollution (Fang, Hao, et al., 2019). Furthermore, decreasing carbon emissions assists in alleviating excessive demand on natural resources, protecting ecosystems, and preserving biodiversity (Xue et al., 2022). Most importantly, effectively controlling carbon emission levels provides more time and space for future societies and ecosystems to adapt. Research has confirmed that addressing environmental degradation can significantly improve health outcomes, with the impact being most pronounced for higher-income groups. Additionally, reducing environmental pollution will further enhance the health promotion effects of socio-economic development. By improving environmental equity, the health disparities caused by unequal socio-economic conditions can be effectively alleviated, promoting health equity across society (Asongu & Odhiambo, 2024). Although climate change poses challenges, by reducing carbon emissions, we can slow its pace and create more opportunities to adapt to its impacts. Thus, effectively controlling carbon emissions is essential not only for environmental protection but also for driving the transition towards sustainable economic development.

In addressing the global challenge of climate change, environmental governance and the control of carbon emissions are not only urgent environmental demands but also core strategies for achieving sustainable development. As a principal driving factor of climate change, scientific research on carbon emissions plays an irreplaceable role in analyzing the impacts of human activities on the global climate system (Yuping et al., 2021). However, with economic progress and improvements in living standards, humans increasingly demand more convenient lifestyles and high-quality goods, necessitating greater industrial production and an expended range of products and services. In other words, world is becoming more and more complex.

1.2 Background of study

1.2.1 Environmental Quality

One of the major global challenges has long been how to achieve a win-win situation between economic growth and environmental protection, enabling sustainable economic development. In the concept of "environmental sustainability" proposed by Hoffmann et al. (2005), the emphasis is placed on the preservation of natural capital, defining environmental sustainability as the necessity of sustainable resource consumption. A series of environmental issues continue to harm ecosystems and threaten life, so achieving environmental sustainability requires ensuring the sustainable use of raw materials while keeping waste emissions within permissible limits to improve human well-being and prevent potential harm. Environmental sustainability is not only about the protection of natural resources but also involves social dimensions. By ensuring the supply of raw materials needed by humans and limiting waste emissions, environmental sustainability aims to enhance human welfare and prevent potential risks. Therefore, humans must learn to live under the conditions regulated by physical environmental protections (Wang & Shen, 2016).

Due to the continuous increase in energy consumption, production, and unsustainable human activities, the environment on which human society depends for survival is facing tremendous challenges. The greenhouse effect, directly related to the carbon footprint, poses a serious threat to the global environment. As the most significant greenhouse gas, carbon dioxide accounts for 76.7% of greenhouse gas emissions, highlighting the urgent need to address this critical issue (IPCC, 2013). Over the past few decades, the excessive rise in CO_2 emissions and greenhouse gas production has led to severe environmental degradation on a global scale. Between 2021 and 2022, global greenhouse gas emissions increased by 1.2%, reaching a record high of 57.4 billion tons of CO_2 equivalent. Similarly, GHG emissions in G20 countries also rose by 1.2% in 2022 (WMO, 2023). It is particularly important to emphasize that countries with higher emissions capacities and responsibilities, especially high-income and high-emission nations, must take more ambitious and rapid actions, while providing financial and technological support to developing countries. Given that low- and middle-income countries now account for more than two-thirds of global GHG emissions, it is crucial to meet their development needs through low-emission growth models (Brunet et al., 2023). According to the United Nations Environment Program (UNEP, 2023), the warming effect of long-lived greenhouse gases has increased by 49% between 1990 and 2021, compared to the 18th century, with 80% of this increase attributed to CO_2. The global average temperature is now more than 1.1°C higher than the pre-industrial average from 1850–1900. The sharp rise in CO_2 emissions and GHG production has become a pressing global issue.

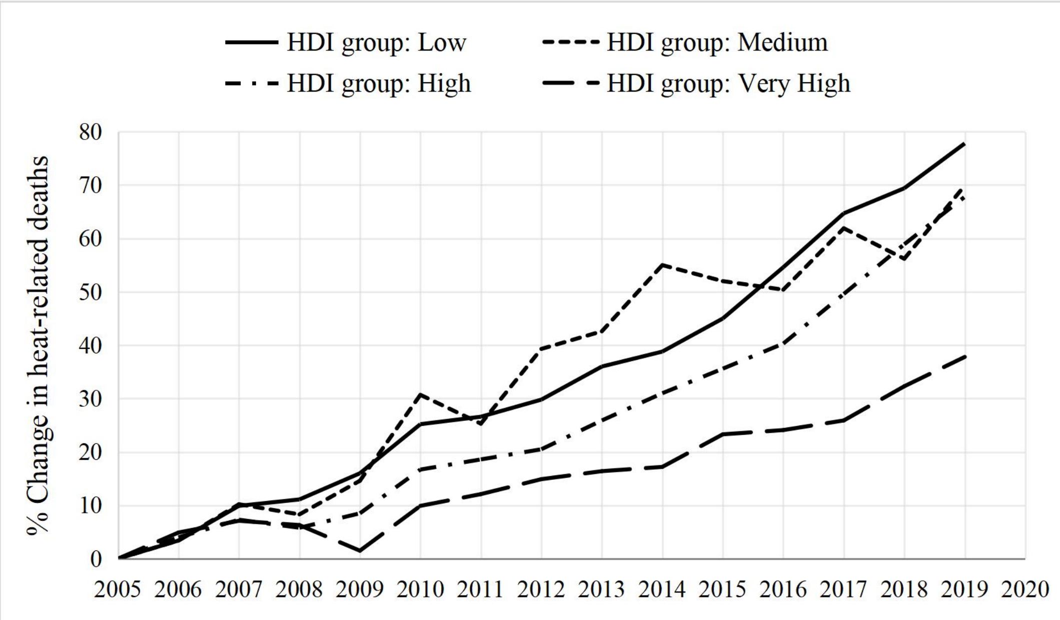

Figure 1.1 Trend of global heatwave-related mortality

[Data source: 2021 Report of the Lancet Countdown; HDI: Human Development Index].

Figure 1.1 shows global heat wave-related mortality, showing how rising temperatures affect human health directly and indirectly. The figure shows that heat-related health issues affect all countries, emphasizing the need for global climate change action. Heatwave mortality is higher in countries with lower development indices, indicating greater challenges in responding to extreme weather events. This also gives international communities and governments a clear path to reduce climate change-related health risks by improving infrastructure, public health, and climate adaptation policies. Although heat wave mortality has increased in developed countries, these countries have better protection measures and emergency response capabilities. This also offers hope for developing countries to mitigate the impacts of environmental degradation offers hope.

Therefore, addressing environmental degradation in developing countries is urgent, as it not only relates to ecosystem protection but also directly impacts public health, economic growth, and social equity. By advancing research on environmental degradation, developing countries can find a balance between economic development and environmental protection. This would help lay the groundwork for securing greater international cooperation and support in global climate governance, contributing to the achievement of sustainable development goals.

1.2.2 Economic complexity

Economic Complexity (EC) is a concept that measures the complexity and diversity of a country or region's economy (Hidalgo & Hausmann, 2009), they define economic complexity as a country's productive capacities and interactions. It is not only about the quantity of goods and services produced, but also about the complexity of these products and the diversity of knowledge and skills required in their production. It shows the diversity and ubiquity of a country's exports. Diversity refers to the number of goods that a country is able to produce and export competitively, while ubiquity refers to the number of countries that have the capacity to export products competitively (Aluko et al., 2023). A complex economy has a variety of rare export products that are not widely exported. This complexity suggests a sophisticated production capability that goes beyond commodity-based economies and implies high technological advancement and industrial diversification (Ghosh et al., 2022). Studies have shown that the economic complexity index not only reflects a country's economic capacity in the production process, but is also closely related to its level of prosperity and economic development (Hausmann et al. 2014). In addition, economic complexity can be used to predict a country's potential for economic growth and long-term prosperity, while at the same time reflecting a country's economic structure (Hidalgo, 2021).

Economic complexity serves as a vital indicator of a country's productive knowledge, influencing economic and social development (Can & Gozgor, 2017). It is linked to higher productivity and innovation, which drive technological progress and enhance energy efficiency (Hidalgo, 2021). This complexity enables regions to produce more advanced goods, fostering faster economic growth, especially in areas specializing in complex products (Hanif et al., 2019). Additionally, economies with greater complexity benefit from diversified export bases, making them more resilient to economic fluctuations and attracting foreign investments, particularly from multinational enterprises (Godil et al., 2020). These complex economies benefit from higher service export diversification in high-income countries and are attractive for new foreign direct investments, enhancing their global competitiveness (Gómez-Zaldívar et al., 2021). This synthesis underscores the integral role of economic complexity in facilitating sustainable economic development and integrating into the global market (Saidi et al., 2020).

Complexity indexes capture production structure information beyond aggregate indicators, making them effective. These indexes recognise the complex nature of activities based on their location and production stages, such as automobile exports involving design, R&D, and supply chain management (Yin et al., 2008). Economic complexity accounts for the level of product sophistication and the developmental stage of industries, enabling a deeper understanding of a country's economic capabilities (Stojkoski et al., 2023). The more high-end the exported automobiles, the higher the economic complexity of the country, as illustrated in Figure 1.2. Additionally, these indices approach emphasizes the role of economic complexity in evaluating export diversification, industry sophistication, and the potential dynamics within industrial sectors, highlighting the strategic importance of advanced industries and knowledge accumulation in central economic activities (Stojkoski et al., 2023).

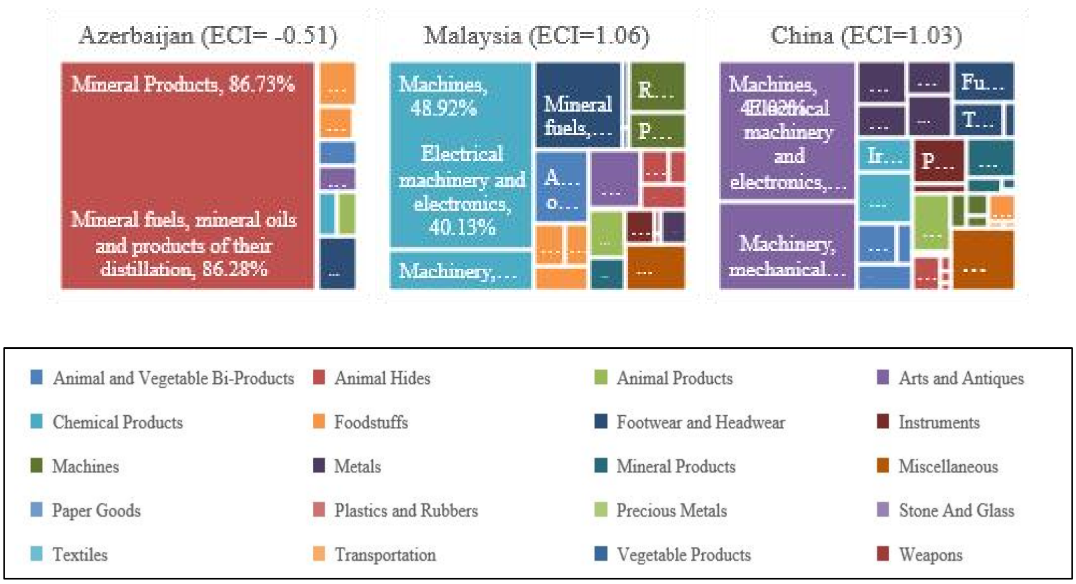

Figure 1.2 Economic complexity index for regions in Azerbaijan, Malaysia and China

Economic complexity index for regions in Azerbaijan, Malaysia, and China. These maps use international trade data classified according to the Harmonized System and estimate subnational-level economic complexity indexes (ECIs) using product complexity index values calculated at the global level and a binary specialization matrix (Mcp) derived for each product. Data available at oec world.

The economic complexity measured by Hidalgo and Hausmann (2009) identifies the diversity and ubiquity of a country's export output as primary metrics, and employs a method of reflection to derive the Economic Complexity Index (ECI) (Hidalgo, 2021). Diversity refers to the number of products a country can produce and export competitively, while ubiquity refers to the number of countries that can competitively export a product (Aluko et al., 2023). According to research from Harvard University's Centre for International Development, the Economic Complexity Index is calculated using data from the United Nations Commodity Trade Statistics Database, the International Monetary Fun, and the World Development Indicators, covering over 130 countries. The economic complexity index has become an influential tool in understanding and comparing the economic structures of nations, providing insights into how countries are positioned in the global economy based on their production and export capabilities (Hausmann et al., 2014).

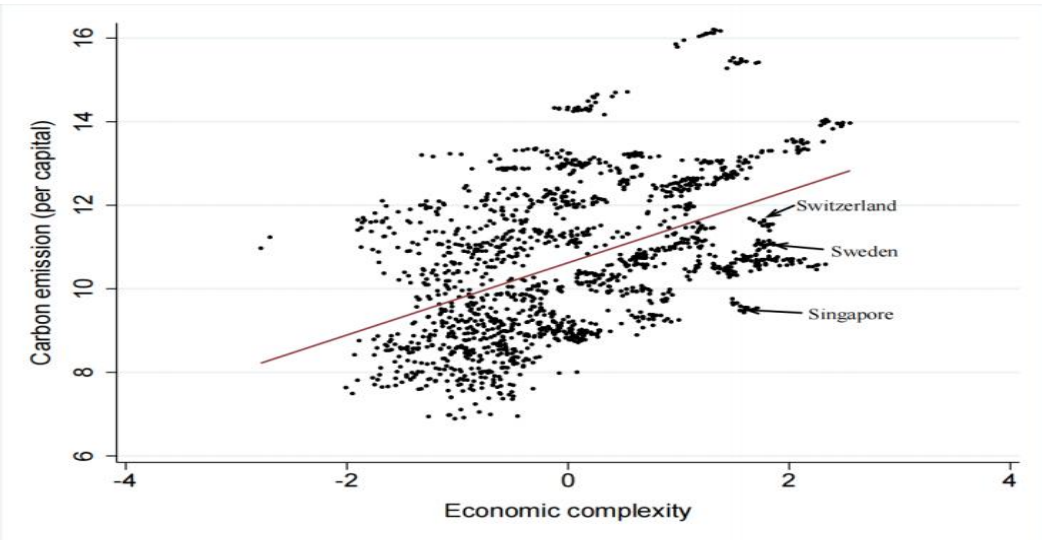

Figure 1.3 Scatter plot of economic complexity and carbon emissions

[Sources: The CO_2 data is sourced form World Development Indicators database; Economic complexity data is sourced from Observatory of Economic Complexity database]

In conclusion, enhancing economic complexity contributes to economic development, attracts foreign investment, and fulfils the demand for a higher quality of life. However, an increase in economic complexity often results in heightened environmental stress. As shown in Figure 1.3, ECI has a tendency to be higher or complicated, implying the more effort to develop and produce more goods and services. This later on may be translated into higher GDP and welfare of the people. On the other hand, it can also be observed that there are countries with high level of ECI but at the same time, enjoy reasonable level of environmental degradation (such as Switzerland, Sweden and Singapore).

This suggests that while economic complexity can drive economic growth and development, it may also suggest environmental consumption. The assumption that economic complexity can have beneficial effects on any economy implies that for these benefits to be fully realized, there should be supported by green innovation, green energy, and high institutional quality.

1.2.3 Green energy

In today's energy-dependent economy, both developing and developed countries are paying great attention to the topic of green energy (Zafar et al., 2022). Green energy is also known as renewable energy. It is explained as energy collected through renewable energy sources such as rain, sunlight, geothermal, wind, waves, etc. with minimal damage to the environment (Zhu et al., 2016). Typically, renewable energy sources provide energy for four different sectors, including transport, electricity generation, water and air cooling/heating, and rural energy services. Compared with other energy sources, although renewable energy is concentrated in large ecological regions and primarily found in a minimal number of countries, the rapid localization of these resources can yield economic benefits, enhance energy security, and mitigate climate change (Zafar et al., 2019). This strategic placement of renewable energy facilities taps into natural resource availability to maximize output while reducing transportation and distribution costs, leading to more efficient and sustainable energy production systems (Yuping et al., 2021).

Green energy development is pivotal for economic growth and improving living standards, as outlined by the International Renewable Energy Agency (IRENA). It creates jobs across various sectors, boosts local economies, and raises living standards in those regions (Zheng et al., 2021; Zhu et al., 2016). Political analyzes suggest that governments advocate for renewable energy transitions to increase employment, incomes, and reduce social inequalities, which in turn can enhance tax revenues. Studies, including those focusing on China and Germany, have found a reciprocal relationship between renewable energy use and economic growth, indicating that renewable energy can lead to long-term gains in energy efficiency and reduce operational costs for businesses, making them more competitive compared to those reliant on traditional energy sources (Zafar et al., 2019; Zhang & Zhou, 2016).

More importantly, renewable energy contributes to reducing the impacts of climate change and slowing the pace of global warming (as illustrated in Figure 1.4). With the gradual increase in the consumption of renewable energy, there is a trend towards a reduction in carbon emissions.

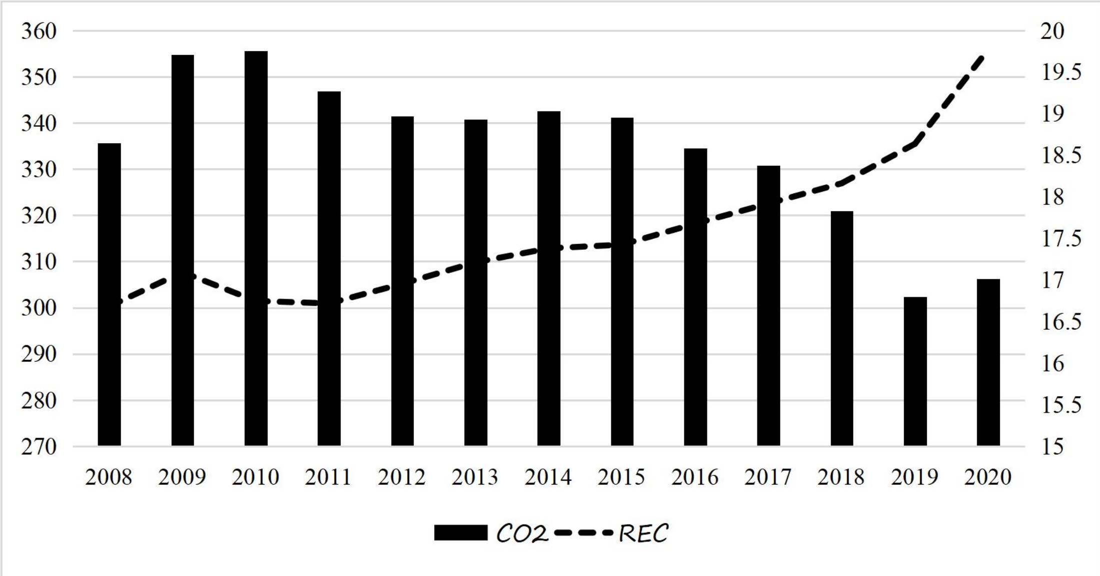

Figure 1.4 Renewable energy consumption and carbon emission trend chart

Researchers believe that renewable energy can balance the negative impacts of increased economic activities on environmental performance by substituting fossil fuels and creating an eco-friendly environment. Renewable energy sources include those with low or even zero emissions. Despite the increasing use of renewable sources like wind, hydro, and solar power for electricity generation in recent years, their share in the total energy supply remains low; in 2018, renewable energy accounted for less than 20% of global electricity generation. The proportion of renewable energy use in overall energy consumption remains low (International Energy Agency, 2021). As renewable energy is considered a mainstream energy source, the low percentage of renewable energy use in the total energy consumption mix presents another threat to developing countries (You & Lv, 2018; Yuping et al., 2021).

Theoretically, renewable energy is considered a pollution-free and potentially unlimited solution to climate change and energy security issues. By utilizing renewable energy in production and manufacturing activities, efficiency can be improved, and growth can be achieved while reducing waste and greenhouse gas emissions (including carbon emissions) (Wang et al., 2023). However, a rising Economic Complexity Index (ECI) is considered a significant threat to environmental performance. As the process of refining and diversifying exported goods increases, so does the demand for energy, ultimately leading to increased energy intensity and emissions (Yasmeen, Zhaohui, et al., 2022; Zheng et al., 2021). Therefore, whether renewable energy can facilitate the transition to a low-carbon economy amidst economic complexity is one of the focuses of this study.

1.2.4 Green Innovation

Technological innovation is widely recognized as a leading and effective approach to enhance resource efficiency and mitigate CO_2 emissions. Technological innovation drives the transition of economies towards the adoption of environmentally sustainable technologies (Lin and Zhu, 2019; Razzaq et al., 2020a). Green innovation encompasses all innovations that pertain to conserving resources and energy in business and economic activities (Razzaq et al., 2021b; Lingyan et al., 2021). Examples of environmental control measures include pollution control (preventing the direct emission of harmful substances into the atmosphere and implementing carbon capture and storage), waste management (i.e. handling, treating, and disposing of waste), clean technology (i.e. adopting changes in production technology), and clean-up technology (i.e. remediation technology) (Schreiber et al., 2016; Chen and Lee, 2020; Costantini et al., 2017; Li et al., 2020). These innovations improve the performance of new and advanced technical applications, resulting in a direct decrease in energy consumption and an increase in energy efficiency (Yii and Geetha, 2017).

Existing literature indicates that technological innovation can drive high-quality economic development (Ding et al., 2021), and is a primary engine of economic growth (Dong et al., 2019). Technological innovation facilitates the continual improvement and advancement of new infrastructure construction, deepens and expands the integration of the digital economy with the traditional physical economy, and promotes the development of emerging industries and business models (Jahanger, Usman, et al., 2022). Additionally, the introduction of new technologies typically enhances productivity and efficiency, enabling businesses to produce more goods or provide more services more rapidly, thus reducing costs and increasing profits (Ding et al., 2021). By enhancing productivity and creating new industries, technological innovation can bring more opportunities and potential for economic growth (Omri, 2018). Romer (1990) explicitly linked technological progress with economic growth. Research has found that technological innovation itself is the result of individual behavior under market incentives, which in turn promotes wealth accumulation. Furthermore, theorists argue that knowledge accumulation, innovation, and research and development are key factors in promoting economic growth. Particularly, the diffusion of product innovation plays a significant role in boosting economic growth (Ornaghi, 2006).

Meanwhile, innovation constitutes an indispensable component in the process of enhancing economic complexity. Economic complexity reflects a country's production structure, and the production structure of each country determines its technology, production potential, and diversification trends (Hidalgo et al., 2007). Thus, enhancements in technological innovation capabilities and knowledge-intensive goods enhance national economic complexity through increased energy efficiency and productivity.

Notably, while technological innovation promotes economic development, it also facilitates the mitigation of environmental degradation and supports sustainable development (Chen & Lee, 2020). Some scholars have demonstrated the importance of technological innovation for achieving sustainable development. These fields cover the societal impacts of technology, information and communication technologies (ICT) with sustainable growth, sustainable development technologies, social entrepreneurship and technology, green energy technologies, and sustainability (Bekhet and Abdul Latif, 2018). Moreover, Omri (2018) found that in high-income countries, technological innovation encourages environmentally friendly production by urging investors to adopt innovative technologies. He also noted that low-income and middle-income economies should earnestly strive to produce and use innovative technologies to balance economic development with environmental protection (Shahbaz et al., 2018) Furthermore, Growth in GDP has led to intensive carbon emissions; however, technological innovation and the utilization of renewable energy sources have made it feasible to mitigate environmental degradation (Yasmeen, Zhaohui, et al., 2022). Similarly, Meng (2022) found that green technology innovation significantly helps reduce greenhouse gas emissions. Their research underscores the importance of investing in new, sustainable solutions to address the issue of greenhouse gas emissions. Therefore, in the long run, the development of technological innovation helps to alleviate environmental issues in developing countries (Hussain and Dogan, 2021).

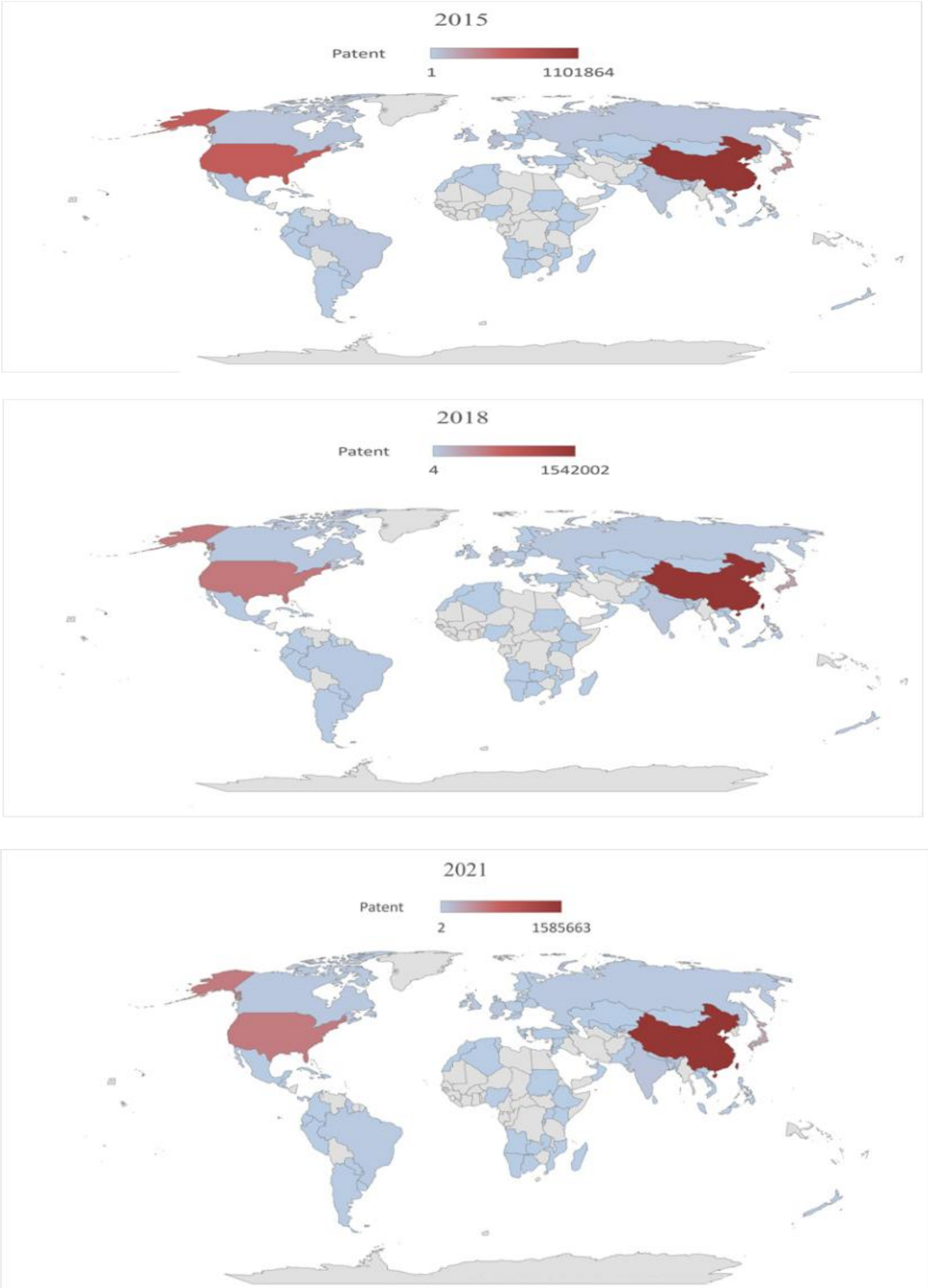

Figure 1.5　Global patent application distribution map

Note: The legend shows the minimum to maximum value of the total number of patents in each year.

Figure 1.5 illustrates the growth trend of global patent applications from 2005 to 2021. It is evident from the graph that technological innovation activities are on the rise worldwide, with the vigor and capacity for innovation steadily increasing.

However, it is puzzling that despite the continuous increase in the number of patents, environmental degradation has not diminished. This situation raises questions about the nature of the innovations being patented and whether they are effectively contributing to environmental sustainability.

Figure 1.5 also depicts the distribution of patent applications around the world from 2015 to 2021. The graph shows no significant change in the distribution of patent numbers across three periods, and the growth in patent numbers per country is not substantial. Furthermore, countries with a relatively high number of patents, such as China, the United States, and Japan, also rank high in terms of total carbon dioxide emissions. This suggests that not all technological innovation projects contribute to environmental preservation. Therefore, it is considered that green technology innovation may be the key factor in balancing economic complexity with environmental degradation.

1.2.5 Institutional quality

Institutional quality is defined as a set of formal (e.g. rules, laws and constitutions) and informal constraints (e.g. behavioral norms, practices and self-imposed guidelines) that together stimulate regularity in individual and societal behaviors (Greif and Kingston, 2011).

Why does the quality of institutions matter? First, entrenched institutions are the fundamental drivers of relative prosperity worldwide. Sound institutions are the cornerstone of global prosperity (Salman et al., 2019). Masron and Nor (2013) demonstrate the importance of institutional quality in economic development. Aqiru (2018) argues that institutions are fundamental determinants of economic performance. Institutional theory can be traced back to the seminal contribution of North (1990, p. 3) who viewed institutions as "the rules of the game in a society or, more formally, ... artificially designed constraints that shape human interaction". This is reflected in the fact that security of property rights or good institutions in competitive markets affect the relative returns to different productive and unproductive economic activities. Thus, the quality of institutions fundamentally drives investment in human and physical capital as well as in innovative activities, leading to large and persistent differences in per capita incomes around the world. It is worth noting that low-quality economic or political systems remain a persistent feature in many societies globally, often attributed to a country's geographical or historical characteristics (Nikolaev & Salahodjaev, 2017; Vu, 2021c). Thus, the persistence of underdevelopment is rooted in the slow evolution of the system (Nunn，2020；Maseland，2021).

Furthermore, the quality of the system reflects the strength and credibility of the Government's commitment to implementing the policy (Xu et al., 2022). The attainment of agreements, conferences, and policies aimed at improving environmental quality largely depends on the quality of institutions responsible for implementing and monitoring policies. Weaknesses in institutional quality can potentially affect environmental policies and regulations (Rafei et al., 2022). Therefore, we consider that institutional quality may be one of the important factors influencing the relationship between economic complexity and carbon emissions.

Some studies suggest that better institutional quality can effectively curb the increase in carbon emissions. Improving governance quality can minimize opportunism, promote cooperative behavior among stakeholders, and enable them to internalize externalities to enhance environmental quality (Panayotou, 1997). Strong political institutions are considered essential tools for curbing market failures (Olson Jr, 1996) and compelling firms to comply with pollution emission control procedures (Welsch, 2004). According to Lau et al. (2014) and (Salman et al., 2019), powerful political institutions are important to minimize the environmental costs of economic development. Flachaire et al. (2014) used data from both developed and developing nations to analyze the function of institutions in driving economic growth. An important component in identifying a country's model is its political system.

Table 1.1 Institutional quality and carbon emissions of some developing countries (in 2020)

	Total carbon emission (CO_2)	**Institutional Quality** (IQ)
Brazil	414138.8	-0.1147726
Thailand	265478.9	-0.1112153
Colombia	79057.6	-0.0448711
Tunisia	59293.9	0.0067543
Indonesia	56319.7	0.031766
Jordan	20974.1	0.0767967
Mongolia	21184.7	0.0912076
North Macedonia	6796.7	0.1416548
Jamaica	5835.6	0.3401645
Namibia	3952.8	0.4412571

Source: Data derived from the original World Bank database; IQ is the average of the variables computed using principal component analysis (PCA).

The Global Governance Index is the main authoritative proxy for the quality of governance in a country's government as a proxy for the quality of the country's institutions. The GGI is published by the World Bank and records data for 215 countries and territories in the world from 1996 to the present. And the index has been widely used in research due to its certain comprehensiveness and comprehensiveness (Azam et al., 2021; Bhattacharya et al., 2017; Dasgupta & De Cian, 2018).

Table 1.1 shows the level of carbon emissions and institutional quality in selected developing countries. From Table 1.1, it can be seen that countries with higher institutional quality (IQ) have relatively smaller carbon emissions. Therefore, this may indicate that countries with higher institutional quality may have more effective policies to manage carbon emissions.

Given that high-quality institutions play a crucial role in driving economic growth, it is also closely related to economic complexity, human capital formation, foreign direct investment and trade diversification (Dias & Tebaldi, 2012; Khan et al., 2020). Therefore, this study suggests that institutional quality may be an important factor in improving the relationship between economic complexity and environmental quality.

1.3 Problem Statement

The escalating issue of global climate change is underscored by the undeniable increase in carbon dioxide concentrations (UNEP, 2023). While the number of disaster events has decreased slightly since 2010, they remain at a high level, and the economic losses caused by natural disasters continue to grow, posing significant threats to people's lives and property safety (UNEP, 2023). In 2022, recorded carbon dioxide concentrations exceeded the critical threshold of 400 parts per million (ppm), reaching 409 ppm (UNFCCC, 2023). The United Nations Environment Program further confirmed the severe trend of global warming in its

2023 Emissions Gap Report, noting that global temperatures are reaching new highs, and that efforts to reduce emissions are grossly insufficient (UNEP, 2023). If current carbon emission levels are not controlled, the global average temperature could rise by approximately 4 degrees Celsius by the end of the 21st century, far exceeding pre-industrial levels (Collins et al., 2013). Excessive greenhouse gas emissions are widely regarded as the primary cause of ongoing adverse climate change(UNEP, 2023). This pressing issue has prompted many national governments to adopt political decisions aimed at reducing emissions, but most pollution still originates from developing economies (Wawrzyniak & Doryń, 2020). Therefore, the task of reducing emissions is especially urgent for developing countries.

Developing countries are often in a phase of rapid economic growth, leading to a significant increase in resource consumption and pollution emissions (Sarkodie & Strezov, 2019). Global carbon dioxide emissions have been on an upward trend and continue to increase, as illustrated in Figure 1.6. However, developing countries generally face challenges such as weak infrastructure, limited technological capabilities, and insufficient environmental governance, making them more vulnerable to the severe impacts of environmental degradation. Environmental issues not only threaten ecosystems but also directly affect the health and livelihoods of vulnerable populations, exacerbating social inequalities (von Borries et al., 2023). At the same time, many developing countries rely on natural resources to drive economic growth, and environmental degradation further undermines their economic sustainability (Fang, Gozgor, et al., 2019). Addressing these issues is urgent; otherwise, more severe ecological and social consequences will arise, hindering these countries from achieving their sustainable development goals. Therefore, studying and implementing effective environmental governance measures can not only alleviate the current environmental crisis but also provide crucial support for these countries' future transition to a green economy.

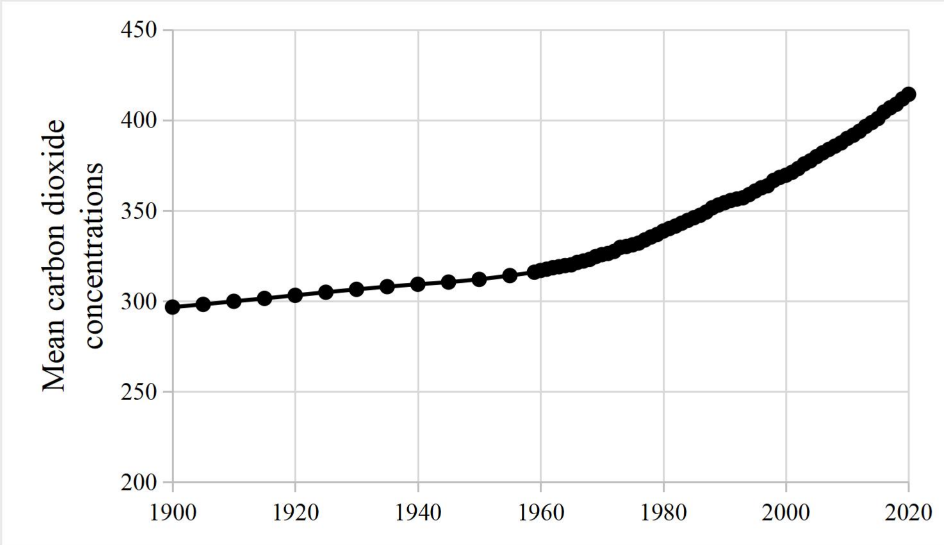

Figure 1.6 Trends in Atmospheric Carbon Dioxide Concentration

[Source: NOAA (https://data.unep.org/climate/essential-climate-variables-ecv/atmospheric-co2)]

Up to now, there has been a substantial body of research on the impact of economic complexity on environmental degradation. Most studies concur that an increase in economic complexity exacerbates environmental deterioration especially in developing countries (Ahmad, Ahmed, et al., 2021; Ahmed, Adebayo, et al., 2022; Balsalobre-Lorente et al., 2018; Doğan et al., 2019; Rafei et al., 2022; Shahzad et al., 2021; You et al., 2022).

As illustrated in Figure 1.3, the diversification and increased complexity of manufactured products, along with the emergence of economies of scale, have contributed to worsening environmental conditions (Swart and Brinkman, 2020; Sadeghi et al., 2020). Therefore, the primary issue in our research is how to reduce carbon emissions while maintaining the rise in economic complexity. Based on the above considerations, we regard green energy, green innovation, and institutional quality as key to addressing this issue.

The development of economic complexity aims to elucidate the production dimensions of economic systems, accounting for the capabilities specific to each country (Hausmann et al., 2014). Higher degree of economic complexity is associated with more complex production structures (Hidalgo & Hausmann, 2009). This framework suggests that structural transformations are likely to affect a nation's level of pollution, signaling a shift towards a technology-intensive and energy-efficient economy. Accordingly, the empirical literature in energy economics extensively explores the relationship between energy consumption, economic growth, and emissions. In the transition to clean energy, renewable resources are central to improving the energy structure and are recognized as a sustainable avenue for growth (Aguirre & Ibikunle, 2014). Considering that renewable energy is critical in enhancing environmental quality and securing national energy safety, its inclusion is imperative in effectively reducing carbon emissions while advancing economic complexity.

Green energy may solve climate change and energy security without polluting. Renewable resources in production and manufacturing can boost efficiency, growth, and waste reduction while lowering greenhouse gas emissions, including carbon emissions (Zheng et al., 2021). The variety of useful knowledge determines an economy's complexity. Complex economies can use advanced modelling and renewable energies to manage knowledge and resources and produce diversified products (Yasmeen, Tao, et al., 2022). Simpler economies use traditional technologies and non-renewable resources to produce goods and cannot manage production knowledge (Neagu & Teodoru, 2019).

However, the adoption of green energy is not uniform (Bhattacharya et al., 2017). The adoption of renewable resources varies based on a country's scientific endeavors, investments, infrastructure, and institutional frameworks (Nastasi & Basso, 2016). Consequently, there are significant disparities in carbon dioxide emissions among countries. Although the usage of green energy is gradually increasing, it is far from achieving the emission reduction targets set by the IPCC.

The literature on economic complexity and carbon emissions is extensive. However, studies examining the role of economic complexity and green energy in achieving carbon reduction targets remain scarce. Different studies have investigated various regions and countries to determine the roles of these two variables in economic growth and sustainable environmental practices. Nevertheless, to our knowledge, no empirical analysis has yet been conducted on carbon reduction targets in developing countries that considers both the economic complexity index and the role of green energy. Moreover, most studies have examined economic complexity and green energy as separate variables without considering their interactions (Murshed et al., 2022; Neagu & Teodoru, 2019). *Therefore, this research specifically seeks to explore whether green energy can moderate the relationship between economic complexity and environmental degradation in developing countries.*

Compared to green energy, green innovation encompasses a broader concept that not only covers the development of new energy technologies but also includes a variety of new technologies, products, services, and processes that promote environmental protection and resource efficiency (Mealy & Teytelboym, 2022). Green innovation can involve energy-saving technologies, production methods that reduce resource consumption, pollution control technologies, and methods for waste recycling and reuse. Innovation has become an indispensable element in managing