THE DYNAMIC INTERRELATIONSHIPS OF C02 EMISSIONS AND RENEWABLE ENERGY CONSUMPTION ON ECONOMIC GROWTH IN G20 COUNTRIES: A PANEL VAR APPROACH

Submitted to the Master's Study Program of Economics at the Faculty of Economics and Business in partial fulfillment of the requirements for the degree of

Master of Arts (M.A.)

Universitas Islam Internasional Indonesia

By :

Joko Susilo

Student ID: 03212210002

UNIVERSITAS ISLAM INTERNASIONAL INDONESIA

DEPOK

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ABSTRACT

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The interrelationship between CO2 emissions, renewable energy consumption, and economic growth is comprehensive, especially for the G20 countries, which contribute to huge global C02 emissions and the world economy. On the other hand, we require a deeper comprehension to formulate policies that harmonize economic expansion with sustainable development. This study will analyze the dynamic interrelationship between CO2 emissions and renewable energy consumption on economic growth in G20 countries. It employs the Panel Vector Autoregression (VAR) approach, covers a period from 1990 to 2022, and involves several fundamental stages. These include the unit roots test to see if the data is statistically sound, the cointegration test to see how the variables have changed over time, and the impulse response function test and variance decomposition to see how shocks to one variable affect other variables. The study's findings show a relationship among CO2 emissions, renewable energy consumption, and economic growth. The data indicate that CO2 emissions have a favourable immediate impact in the short term, resulting in higher GDP and greater economic activity, than C0 emissions and GDP are negative in the long term. Furthermore, we confirm that the short-term relationship between renewable energy consumption and GDP is positive; in contrast, using renewable energy sources does not positively impact economic expansion in the long run. Therefore, G20 countries need to take action to formulate renewable energy policies for economic growth to achieve sustainable development and reduce CO2 emissions while promoting economic growth, whether short-term or long-term.

Keywords: *Economic Growth, C02 Emissions, REC, Panel VAR Analysis, G20 Countries*

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LIST OF ABBREVIATIONS

GDP = Gross Domestic Product
REC = Renewable Energy Consumption
TO = Trade Openness
URB = Urbanization
FDI = Foreign Direct Investment
WDI = World Bank Indicators
EKC = Enviromental Kuznet Curve
VAR = Vector Autoregression
FMOLS = Fully Modified Ordinary Least Squares
DOLS = Dynamic Ordinary Least Squares
GMM = Generalized Method of Moments
ARDL = Autoregressive Distributed Lag
ECM = Error Correction Model
ANFIS = Adaptive Neuro-Fuzzy Inference System
PMG = Pooled Mean Group
ASEAN = Association of Southeast Asian Nations
ARDL = Autoregressive Distributed Lag
ECM = Error Correction Model
ANFIS = Adaptive Neuro-Fuzzy Inference System
LSE = Least Squares Estimate
PMG = Pooled Mean Group
PVAR = Panel Vector Autoregression
IRF = Impulse Response Function
FEVD = Forecast Error Variance Decomposition
AIC = Akaike Information Criterion
BIC = Bayesian Information Criterion
ADF = Augmented Dickey-Fuller
PP = Philips-Perron
HQC = Hannan-Quinn Criterion
FPE = Final Prediction Error
LR = Likelihood Rat

CHAPTER I

INTRODUCTION

1.1 Research Background

Economic growth is a primary goal of economic policy that links to higher levels of resource use (Alakbarov et al., 2024). In addition, a rise in carbon dioxide emissions will negatively affect economic growth (Alyasari & Alzawbaee, 2020). This indicates that the increase in C02 emissions indicates that an increase in fossil fuel consumption and industrial activity is causing climate change, which can decrease economic growth. In this decade, environmental degradation has significantly increased, raising worries about global warming & climate change (Mitić et al., 2022). For instance, the G20 countries are estimated to be eighty-five percent of the global GDP and responsible for up to eighty percent of carbon emissions in the energy sector worldwide (Sucahyo & Arsala Rahmani, 2023). In addition, the Paris Agreement was implemented in 2015 due to the CO2 emissions issue. This agreement requires that countries worldwide increase their awareness of the challenges posed by climate change issues (Adebayo et al., 2022). The G20 countries are a group of countries with substantial economic power and have a considerable environmental impact, notably climate change. On the other side, change is needed to address global climate issues by transitioning to renewable energy sources. Previous research by Wang et al., (2024) shows that all countries are beginning to see that climate change is becoming a global issue; therefore, the use of fossil fuels is the leading due of environmental damage in several countries around the world. Figure 1 shows the total GDP growth of G20 countries from 1990–2022.

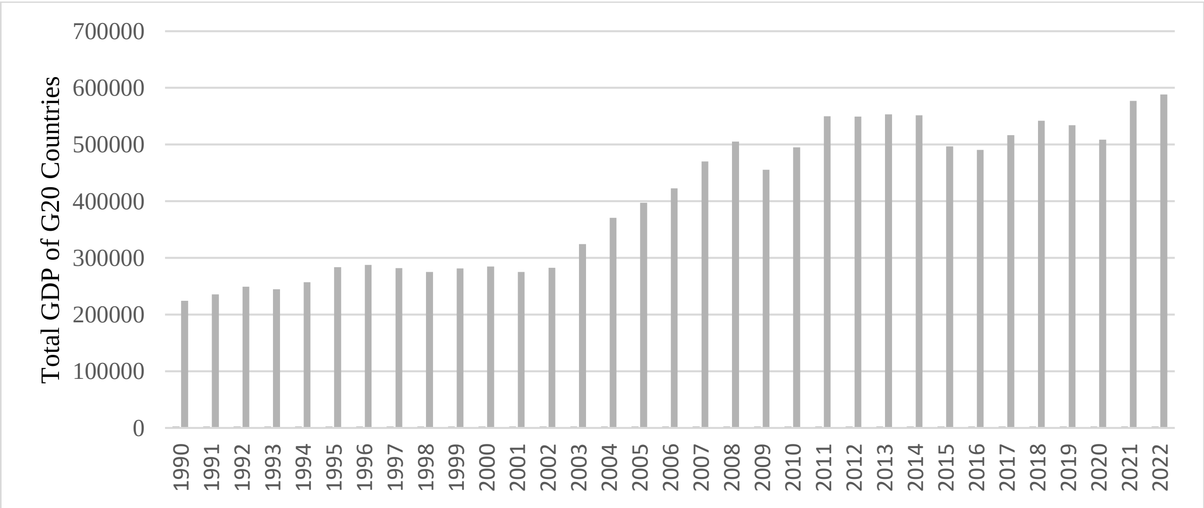


Figure 1.1
Total GDP of G20 Countries (Current US$)
Data Sources: World Bank Indicators (2024)

In this figure for the period 1990–2022, there was volatility in the growth of total GDP in the G20 countries, whereas in 1990–2000, there was quite fluctuating growth. Furthermore, the period 2001–2008 was a period of relatively strong growth for the G20 countries, where many countries experienced sustainable growth before the worldwide financial crisis in 2008. The G20 countries took action to prevent the financial crisis that occurred in 2008 from becoming a depression (Bery et al., 2019). However, there were concerns about global trade growth after the 2008 financial crisis. 2008, G20 countries began implementing several fiscal and monetary policies to stimulate economic recovery. Besides, several G20 countries have implemented measures to stabilize the financial system, including regulations and low interest rates.

Between 2008 and 2019, the G20 countries experienced a period of quite fluctuating economic growth, and a precipitous decline transpired in 2020 due to the impact of COVID-19, which hit almost all countries in the world and resulted in global economic disruption, including reduced economic activity and regional quarantines. This is related to Taylan et al. (2022) the pandemic, which has impacted G20 countries, including inflation, unemployment, GDP fluctuations, spending delays, and some government policies related to monetary emissions. The G20 economies rebounded strongly in 2021, with many countries reporting substantial GDP growth as they lifted pandemic-related restrictions. Figure 1 shows that the global economy grew by approximately 1.93% in 2021, with G20 countries contributing significantly from 577332.012 9 (GDP Per Capita in US$) to 588474.4033 (GDP Per Capita in US$). In addition, if the country's gross domestic product has increased significantly, this will directly impact the increased for carbon dioxide emissions.

This is supposed by Aye & Edoja, (2017) that economic growth is positively correlated with CO2 emissions, and this correlation grows stronger as economic growth rises. Therefore, the commitment of the G20 countries to climate change is expected to reduce global emissions by 50% by 2030 and implement strategies to achieve net zero emissions (UNDP, 2021). In summary, economic growth is positively correlated with CO2 emissions and is accompanied by increased emissions. Therefore, those that emit the most significant amounts of CO2, such as the G20 countries, need to take decisive action to cut carbon emissions without interfering with their economic operations. Nevertheless, the G20 countries are obligated to execute strategies and initiatives with a particular emphasis on sustainable growth and climate change mitigation in the world. This is supposed by Alajlan & Alreshaidi, (2022) that in the short and medium terms, the relationship between unidirectional causation favorably affects the link between carbon dioxide emissions and economic growth. For instance, a one percent boost in economic growth would cause a three-point three percent spike in carbon dioxide emissions both now and in the long run.

One of the main objectives of economic policy is economic development, which is usually associated with increased resource consumption (Alakbarov et al., 2024). In addition, High economic growth and an increase in population will directly increase fossil fuel energy consumption, contributing to increased C02 emissions. In addition, there is a need for a concrete policy to encourage energy efficiency so that measures to reduce C02 emissions will not worsen economic growth (Aye & Edoja, 2017a). On the other hand, renewable energy sources help to reduce C02 emissions, around sixty percent of all greenhouse gas (GHG) emissions globally (Adebayo et al., 2022). This indicates that concrete steps are needed to mitigate climate change because C02 emissions are the highest contributor to global greenhouse gas emissions.

This is related to studies by Marinaș et al. (2018), which indicate a direct correlation between long-term economic growth and the use of renewable energy. This shows that when countries start investing in renewable energy sources, they will experience economic growth due to using renewable energy, which can increase energy independence and stimulate economic growth for sustainable development. This phenomenon follows the EKC hypothesis, which describes that when people experience an increase in income, it will directly lead to environmental degradation, but when people have reached a certain income, they will begin to give more value to environmental quality, where the environment begins to gradually improve even though opinions continue to increase (Alakbarov et al., 2024).

The increase in renewable energy and economic development increases C02 emissions, which can increase C02 emissions in developing countries (Gillani & Sultana, 2020). The findings seem to conflict because a rise in the use of renewable energy and economic growth might lead to increased carbon dioxide emissions. Furthermore, the shift to renewable energy will take some time since certain countries continue to rely on fossil fuels for their monetary needs. This is related to Feriansyah et al., (2022a) the impact of GDP in ASEAN countries on CO_2 emissions has a high elasticity of 0.617%, indicating that a 1% increase in GDP will cause the results to increase by 0.617%. This study states that there is a significant relationship between GDP and C02 emissions in ASEAN countries, with an elasticity level and economic growth in ASEAN countries, emissions will increase proportionally. This shows that economic growth can indirectly encourage environmental degradation, so preventive measures must be taken to reduce C02 emissions so that they can be implemented simultaneously in sustainable economic development.

Another of the results by Ntanos et al. (2018) indicates a significant correlation between the consumption of renewable energy sources and economic growth. Specifically, high economic growth leads to an increase in renewable energy consumption, while low economic growth tends to have a relatively small impact on renewable energy consumption. The study results indicate that countries with high economic growth consume more renewable energy. In contrast, countries with low economic growth tend to impact renewable energy consumption more significantly. In addition, the short-run two-way causality relationship of available energy and employment to GDP provides employment opportunities (Mitić et al., 2022). As a result, energy changes can benefit a country's GDP and increase job opportunities.

The research findings by Niyonzima et al. (2022) show that energy consumption is essential to economic growth because the growth of Germany, the UK, the USA, Canada, China, Egypt, Nigeria, South Africa, Kenya, and Rwanda is highly dependent on energy. In addition, renewable energy sources are the primary source of income for the European Union. In fact, renewable energy has a positive impact on economic growth of 58% in Australia, Canada, Japan, Germany, United Kingdom, United States, Sweden, Netherlands, Ireland, India, South Africa, Spain etc (Shahbaz et al., 2020). In other words, it is probable that a nation will experience substantial economic expansion if it transitions to renewable energy. Furthermore, the government and relevant stakeholders may benefit from the positive and substantial impact that the transition to renewable energy can have on economic growth.

In conclusion, to reduce CO2 emissions, all countries should prioritize the implementation of a more efficient energy transition (L. Wang et al., 2024). Furthermore, renewable energy consumption is one potential factor that could lead to a reduction in CO2 emissions. This is related to (Islam et al., 2023) propose that utilizing renewable energy sources has the potential to decrease CO2 emissions. Therefore, maximizing REC can reduce CO2 emissions, and understanding this problem requires a more comprehensive understanding of how renewable energy affects G20 countries.

2.2 Problem Statement

In the current era, various issues regarding climate change are constantly being discussed on the G20 agenda, where it is essential for policymakers to indirectly consider the relationship between climate and the country's economic performance. Additionally, the impact of environmental degradation has made environmental issues a topic of debate in modern times, whether in developed or developing countries (Osobajo et al., 2020). For instance, the G20 countries represent over eighty percent of the global GDP and have contributed to almost eighty percent of carbon emissions in the global energy industry (Sucahyo & Arsala Rahmani, 2023). Furthermore, two problems are still faced by the G20 countries: a) The G20 countries have different policies and commitments from each other, which has an impact on disharmony in global efforts to reduce CO_2 emissions without reducing GDP, b) The G20 countries still have a significant problem: the transition from fossil to renewable energy. Although many G20 member countries have committed to achieving targets, they are often left behind due to several obstacles, such as inadequate infrastructure, dependence on fossil fuels, and investment and technology challenges. In addition, several developed countries that have entered the G20 have ambitions to achieve net zero, while several developing countries are still facing challenges in meeting lower targets where their sources of income come from fossil energy, so this disharmony can hinder the acceleration of renewable energy. The advantage of employing renewable energy sources is to reduce CO_2, which can help reduce the emission of C02 without reducing GDP. In addition, to address these challenges, it is necessary to fully know the impact of renewable energy and CO_2 emissions on GDP in G20 countries. Therefore, it is important to study the impact of CO_2 emissions and renewable energy consumption on economic growth in G20 countries.

2.3 Research Questions

1. What is the short-term and long-term impact of C02 emissions on Economic Growth in G20 Countries?
2. What is the short-term and long-term impact of Renewable Energy Consumption on Economic Growth in G20 Countries?

2.4 Study Objectives

1. To examine the short-term and long-term impact of C02 emissions on Economic Growth in G20 Countries

2. To examine the short-term and long-term impact of Renewable Energy Consumption on Economic Growth in G20 Countries

2.5 Relevance of the Study

The significance of this research rests in examining the dynamic interrelationships of C02 emissions and renewable energy consumption on economic growth in G20 countries in the short term and long term. In addition, this study seeks to fill a significant research need in the existing body of literature by investigating the influence of G20 countries' GDP on C02 emissions and REC. Furthermore, researchers anticipate that the study will have significant ramifications for G20 countries and associated parties, providing a comprehensive understanding of the elements contributing to CO2 emissions and proposing more impactful and efficient policies and actions. Hence, the results of this study possess the capacity to enlighten decision-making processes and promote sustainable growth, not only within G20 countries but also in other developing countries confronted with comparable obstacles.

2.5.1 Theoretical Benefit

This study has the potential to provide supplemental material for researchers working in university settings. Additionally, it will help us better understand the variables that lead to increased and reduced economic development in G20 countries.

2.5.2 Practical Benefit

Society: The study can provide new knowledge in sustainable growth by emphasizing harmonizing economic growth with environmental preservation.

Investors: This study can provide insight and knowledge on how the dynamic interrelationship between CO2 emissions and renewable energy consumption affects economic growth in G20 countries in the short and long term. This information can also help investors decide to invest in renewable energy projects.

Policymakers: This study informs several policy decisions by providing insights on reducing c02 emissions without lowering GDP. On the other hand, policymakers can use these findings to develop several innovations to encourage renewable energy consumption, reduce carbon emissions, and increase GDP.

Environmental activists and NGOs: This study can provide some information and knowledge on advocacy efforts to support the widespread use of renewable energy sources and reduce carbon emissions without reducing GDP.

2.6 Outline of Study

The thesis outline of the study is structured as follows: Chapter 1 – Introduction, problem statement, and research gap; Chapter 2 Literature review; Section 3 Grand theory & research method. Section 4 results and discussion. Section 5, Conclusion, and Section 6, Limitations and Future Recommendation.

CHAPTER 2

LITERATURE REVIEW

This chapter will explain an in-depth review of the available literature sources on GDP, CO2 emissions, and renewable energy consumption, as well as three variables of control, such as TO, URB, and FDI. In addition, our review focuses on the components of GDP and the relationship between C02 and REC to obtain more accurate information on previous research results and research gaps and to understand some factors that increase GDP with C02, REC, TO, URB, and FDI.

2.1 Theoretical Background

In previous research by (Mendoza et al., 2021; Supроń & Myszczyszyn, 2023; Vo et al., 2019; Yan et al., 2022) shows that the Environmental Kuznets Curve (EKC) hypothesis has been used in several studies to test the correlation between economic growth and carbon emissions during growth periods. Therefore, the EKC Curve Hypothesis tests the correlation between economic progress and environmental degradation. Because of that, the idea is an inverted U-shaped curve, which shows that as countries experience economic growth, there is an initial increase in environmental degradation, followed by a subsequent decline as income levels increase and technology advances significantly. It can be seen in Figure 2.1 below:

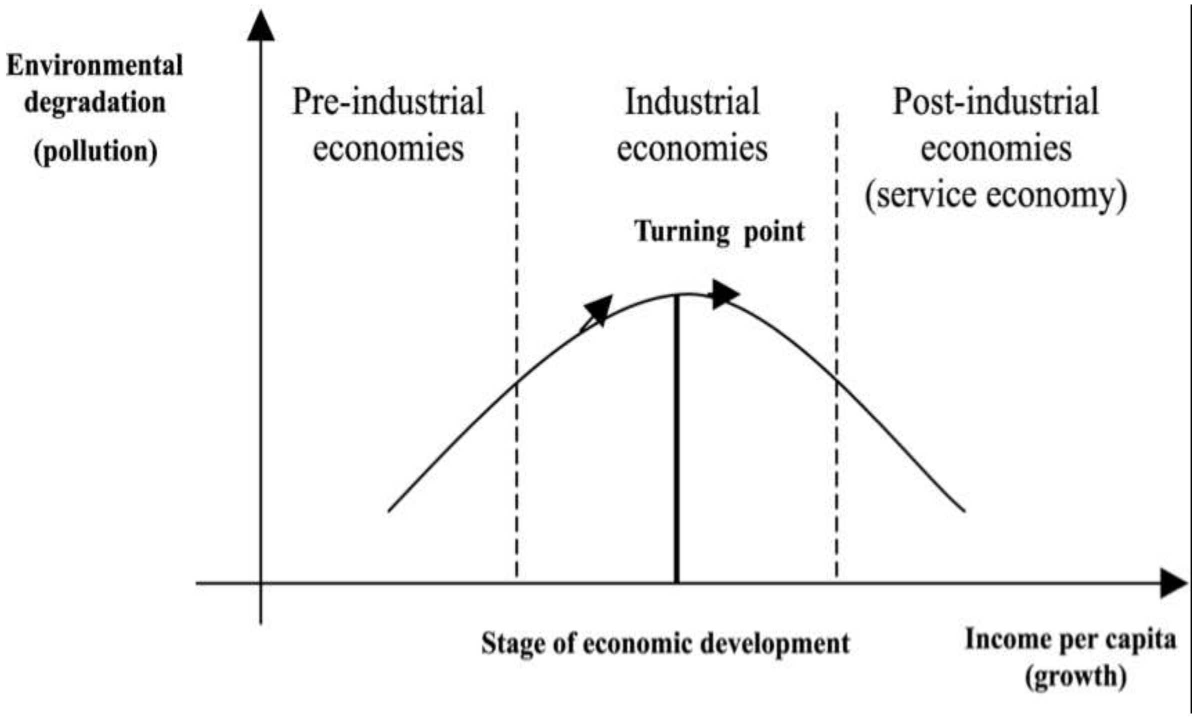


Figure: 2.1 Environmental Kuznets Curve (EKC)

Sources : (G. M. Grossman & Krueger, 1995)

The Environmental Kuznets Curve (EKC) theory posits that the correlation between environmental deterioration and economic growth exhibits a pattern like an inverted U-shaped curve (Grossman & Krueger, 1995), the EKC turning point is a precise technique that may be used to estimate the influence of policies in some countries that are similar to one another in terms of policies, energy, and wealth, as well as on individual countries that have a robust economic structure (Mendoza et al., 2021). Furthermore, an inverted U-shaped relationship between economic growth and environmental sustainability is assumed for GDP per capita and C02 emissions (Islam et al., 2023). In conclusion, this assertion asserts a correlation between environmental damage and economic growth. In order to promote sustainable development and maintain a balance between economic growth and environmental preservation, policymakers should develop policies that align with the inverted U pattern.

Based on this hypothesis, during the first phases of economic growth, there is a tendency for environmental degradation and pollution to rise. This hypothesis implies that there is a negative correlation between economic growth and environmental degradation, but only up to a certain threshold, which is related to the posits inverted U-shaped curve by the EKC hypothesis, where economic growth will be increasing after the country is aware of using renewable energy resources. This is supposed to Adebayo et al., (2022) that renewable energy harms CO2 emissions and there is no correlation between REC and CO2 emissions. To put the premise of the research to the test, the current study makes use of the EKC theory, which is also based on the prior research literature.

2.2 The Nexus of C02 Emissions on Economic Growth

Numerous studies conducted by various researchers over the past few decades have examined the relationship between C02 emissions and GDP emissions. Panel data analysis conducted for the period 2000–2022 reveals a clear positive relationship between the Gross Domestic Product (GDP) and carbon dioxide (CO2) emissions in G20 countries (Pertiwi et al., 2024). Research shows Saidi & Hammami, (2015) that economic growth, CO2 emissions, and energy consumption complement each other. In addition, economic growth and CO2 emissions have a statistically significant favorable influence on energy consumption in the 58 selected countries. Therefore, a sustainable economic strategy is necessary to address the environmental effect of economic development, promote energy efficiency, and embrace renewable energy sources to minimize CO2 emissions while simultaneously boosting economic growth.

Economic growth is proof of a country's progress in development, but it also raises concerns about CO_2 emissions issues (Feriansyah et al., 2022a). This shows that economic growth is often measured as a benchmark of a country's development progress, representing an increase in living standards and overall welfare. However, the higher a country's economic growth, the more significant the increase in CO_2 emissions, which will contribute to climate change in that country. Previous research by Alyasari & Alzawbaee (2020) shows that an increase in carbon dioxide emissions will negatively impact economic growth, whereas energy consumption positively impacts carbon dioxide emissions.Therefore, a rise in carbon dioxide emissions leads to a decline in economic growth, which, as the quantity of carbon dioxide emissions released into the atmosphere grows, will result in various adverse repercussions and might cause the economy to move in an unstable and sluggish manner. However, certain implications have arisen due to the rising costs connected with climate change adaptation and mitigation, as well as changes in consumer behavior and problem patterns in several nations throughout the globe.

The other research shows no causal relationship between economic growth and emissions (Mendoza et al., 2021). However, a positive correlation exists between GDP per capita, employment, and CO_2 emissions. In other words, the results of the study suggest that the quantity of carbon dioxide emissions increases in conjunction with the expansion of the economy (as measured by GDP per capita) and the number of employed individuals. However, there is no direct cause-and-effect relationship between the expansion of the economy and the emission of carbon dioxide. In contrast, research by Mardani et al., (2018) indicates a positive correlation between economic growth and CO_2 emissions in G20 countries. This shows that there is a positive relationship between GDP and CO_2 in the G20 countries, even though several G20 members have implemented renewable energy, which, along with economic growth, also indirectly increases CO_2 emissions in the G20 countries. Another study by Feriansyah et al., (2022a)) indicates a positive correlation between GDP growth and CO_2 emissions, which ultimately peak before declining. This research demonstrates a positive correlation between a 1% rise in GDP and a 0.06173% increase in CO_2 emissions. In other words, the GDP growth rate will tend to increase in CO_2 emissions, but the increase in CO_2 emissions will increase slower. However, this study also states that the relationship between GDP and C02 will eventually peak and decline if the country uses technology to maximize renewable energy.

For instance, in Saudi Arabia, a connection between unidirectional causation positively influences the link between economic growth and carbon dioxide emissions in the short and long term. For example, a one percent rise in GDP will result in a three-point three percent increase in carbon dioxide emissions in both the short and long term (Alajlan & Alreshaidi, 2022). This paper emphasizes the need to look at the link between CO2 emissions and economic growth to create policies that can strike a compromise between environmental sustainability and economic development. In addition, economic growth has a negative impact on C02 emissions when the economy is in a low growth regime, but a positive effect when it is in a high growth regime (Aye & Edoja, 2017a). This demonstrates that there is a correlation between economic growth and carbon dioxide emissions, resulting in a decrease in carbon dioxide emissions when the economy is experiencing minimal growth. Conversely, when the economy is at its peak, economic expansion will result in an increase in CO2 emissions as a result of an increase in energy consumption and investment in industries that generate pollution during the production process. Additionally, the economic conditions of a country can determine the positive and negative effects of economic growth.

The correlation between economic growth, rising CO2 emissions, and energy consumption is well-established. A rise in CO2 levels is known to have detrimental environmental effects (González-Álvarez & Montañés, 2023). It states a solid and inseparable relationship exists between economic growth, energy consumption, and increased CO2 emissions. As the economy grows, energy consumption will automatically increase, increasing CO2 emissions. This can lead to climate change, pollution, and natural habitat destruction. Therefore, countries must adopt concrete measures to reduce environmental impacts while increasing economic growth. Using the Granger causality test, the study found a causal relationship between economic growth, urbanization, and CO2 emissions (Khoshnevis et al., 2019). This research shows that there are findings that use the Granger causality test to find a causal relationship between economic growth, urbanization, and CO2 emissions. Therefore, it shows that if one variable changes between the three variables statistically, it is assumed to change the other variables. In other words, this study explains that economic growth is aligned with urbanization, where economic growth or urbanization can increase CO2 emissions.

The research findings by Mitić et al., (2022) suggest a two-way Granger causality relationship between CO2 emissions, hence the need for a policy that can positively address environmental damage that cannot be repaired quickly and the need for time to overcome it.

The results explain the need to take proactive measures in the long term to reduce the impact of climate change, so policymakers should adopt practices that address environmental degradation and promote sustainable development. In other words, we can reduce the negative impacts of climate change so that it can have a gradual positive impact on economic growth. Furthermore, there is a U-shaped relationship between economic growth and CO2 emissions in developing countries, where emissions can begin to fall with increases in income and technology, as well as the implications of effective policies (Aye & Edoja, 2017a). If the company improves energy efficiency, it will indirectly reduce the environmental burden, encourage environmental investment, possibly lower the carbon tax burden, and improve the company's reputation (Zhang et al., 2015). If a country has reached the middle income level, they will be more inclined towards addressing air pollution, so it requires a considerable amount of money to deal with air pollution effectively and efficiently (Alakbarov et al., 2024). In conclusion, it is possible to demonstrate that it is essential to take into account the connection between economic development and environmental sustainability. This is because, in addition to the rise of wealth, there is a point at which economic expansion may have a good influence on the environment.

H0: There is no correlation between CO2 emissions and economic growth in G20 countries, whether long-term or short-term.

H1: The association between CO2 emission factors and economic growth in G20 countries may be seen over the long and short term.

2.3 The Nexus of Renewable Energy Consumption on Economic Growth

Prior research has undertaken many studies to examine the influence of renewable energy consumption (REC) on Economic Growth. Renewable energy can reduce CO2 emissions only in the short term but has no impact on long-term environmental quality, and there is no relationship between renewable energy and environmental damage (Pata et al., 2022). On the other hand, REC shows that renewable energy consumption positively impacts economic growth in the Visegrad countries (the Czech Republic, Hungary, Poland, and Slovakia). Therefore, it has a particularly positive long-term impact on GDP in Visegrad countries (Suproń & Myszczyszyn, 2023). Besides, Developing countries should be able to take priority investment steps to boost GDP and reduce CO2 emissions, and governments and stakeholders should be able to work together to find new renewable resources (Pertiwi et al., 2024).

Consequently, renewable energy consumption is a method by which economic growth can result in environmental sustainability. The Visegrad countries' positive influence on renewable energy consumption is a model for developing countries to implement economic and environmental sustainability immediately. This is related to studies by Marinaș et al. (2018), which indicate a direct correlation between long-term economic growth and the use of renewable energy. However, in the short term, there is an inverse causal link and no clear causation between economic growth and renewable energy consumption. Therefore, when a country switches to renewable energy, it tends to experience sustainable economic growth over time. Another result of research by (Shahbaz et al., 2020) is that It is crucial to create policies that can support implementation towards development and environmental sustainability through policies adopted from other nations that have engaged in sustainable economic activities, even if all nations that are striving for a renewable energy transition with low carbon emissions should have policies that can inspire implementation towards development and environmental sustainability.

Another study Shahbaz et al.,(2020) examined renewable energy's significant and positive impact on economic growth. Besides, effective policies and the U-shaped relationship between economic growth and CO2 emissions in developing countries can decrease emissions as income and technology increase. Consequently, it is impossible to overstate the beneficial impact of renewable energy on GDP growth. Furthermore, the U-shaped relationship between GDP growth and CO2 emissions provides developing countries with a distinctive opportunity to bypass conventional fossil fuel-based development routes and directly transition to renewable energy sources. This will enable some countries to capitalize on a multitude of new market opportunities, encourage innovation and investment, and reduce their dependence on foreign resources. For instance, Sweden is one of the most sustainable countries in the world, and then Sweden desires to reduce fossil fuels and impose a more comprehensive carbon tax and tax reform (Adebayo et al., 2022). This indicates that Sweden is the first country to take a step ahead in reducing its dependency on fossil fuels, demonstrating that Sweden is one of the most sustainable G20 countries. Furthermore, the efforts that Sweden is making may be transferred to all of the G20 member nations that are still transitioning to renewable energy without hindering the country's economic growth.

Furthermore, one of the elements preventing the implementation of renewable energy sources is the lack of financial resources in EU nations, whose primary source of revenue still comes from non-renewable energy sources (Ntanos et al., 2018). This statement highlights the significant barriers that impede the adoption of energy sources in the European Union. It emphasizes the urgent need to switch to sustainable renewable energy immediately, prompting EU countries to take preventive measures and allocate sufficient financial resources to renewable energy projects. In addition, renewable energy sources are the primary source of income for the European Union. In fact, renewable energy has a positive impact on economic growth of 58% in Australia, Canada, Japan, Germany, United Kingdom, United States, Sweden, Netherlands, Ireland, India, South Africa, Spain etc (Shahbaz et al., 2020). In other words, if a country transitions to renewable energy, it is likely to experience large economic growth. In addition, the transition to renewable energy can have a positive and significant impact on economic growth, which can benefit the government and relevant stakeholders.

H0: There is no correlation between REC factors and economic growth in G20 countries, whether in the long-term or short-term
H1: The association between REC factors and economic growth in G20 countries may be seen in the long and short term.

2.4 The Nexus of Trade Openness on Economic Growth

Several recent studies have examined the correlation between trade openness (TO) and CO_2 emissions in developing and developed countries. The correlation between trade operations and environmental degradation can be explained in three ways, according to (Grossman & Krueger, 1991), as the scale effect shows that trade openness can increase economic growth and environmental degradation through increased investment and trade liberalization. Second, the composition effect: if there is an increase in trade openness in developing countries, imports and exports can be profitable and impact increasing CO_2 emissions because they are not environmentally friendly. Finally, there is the technical effect, where trade openness illustrates that developing countries can reduce environmental degradation by importing environmentally friendly technology to reduce CO_2 emissions.

Proof of this is the research conducted by Adebayo et al. (2022), which found that the impact of trade openness on CO2 emissions in Sweden is consistently negative across all levels of trade openness and CO2 emissions. This is supposed by Naveed & Shabbir, (2006) trade openness is one way to increase economic growth in developed countries. Therefore, trade openness in developed countries can increase economic growth and lead to higher productivity and more affordable prices for all industrial products. In addition, trade openness not only attracts investors to invest but also provides employment opportunities and increases the value of exports In contrast, in developing countries, there is a negative correlation between trade openness and CO2 emissions in India (Karedla et al., 2021). This statement explains the negative impact of trade openness in Indian countries; the possibility of trade openness will increase C02 emissions even though economic growth will increase with trade openness. In another research by Nketiah et al., (2020) trade openness is the main factor that can affect economic growth; the p value is 0.047, indicating that trade openness has a significant relationship to economic growth. This explains that trade openness has a significant positive impact on economic growth. In other words, if a country can increase its trade openness, the country will indirectly experience faster economic growth.

2.5 The Nexus of Urbanization on Economic Growth

Urbanization is a dynamic moderation phenomenon in which social and economic capabilities from rural areas move to urban areas. In addition, high population increases can increase C02 emissions (Khoshnevis et al., 2019). Many previous studies have investigated the impact that urbanization has on economic growth. It means that many studies have been conducted to understand the conditions of the impact of urbanization where, over time, many people move from rural to urban areas. In addition, there is a relationship between growth and economic growth in urban areas, so people move from rural to urban areas. This is related to Zhao & Wang (2015) that urbanization and economic growth significantly impact increasing energy consumption in China. Apart from that, there is a need for a policy to prioritize optimizing industrial structures, increasing energy efficiency, and restructuring the energy system to achieve sustainable development.

Research by Khoshnevis Yazdi & Dariani, (2019) shows a two-way causal relationship between economic growth, urbanization, and CO2 emissions. The relationship between the economy, urbanization, and CO2 emissions is one of the interrelated events in the Asian region.

Urbanization, on the other hand, has increased due to economic growth, which encourages people to move from villages to cities to get better job opportunities, even though the standard of living is also higher. However, urbanization can increase energy consumption and infrastructure development, which will have a direct impact on CO2 emissions. Another research by Alajlan & Alreshaidi, (2022) In the long term, the link between economic development and urbanization in Saudi Arabia demonstrates a causal relationship that works in both directions. This relationship is a two-way causal interrelationship. There is, however, a beneficial influence that economic growth has on urbanization in the short term, and there is no statistically significant connection that exists between urbanization and economic growth.

Economic growth is related to the EKC hypothesis, and the Environmental Kuznets Curve (EKC) hypothesis has been used in several studies to test the correlation between economic growth and carbon emissions(G. Grossman & Krueger, 1994). This is supported by Alajlan & Alreshaidi (2022). The analysis revealed that urbanization boosts economic growth, so the Environmental Kuznets Curve (EKC) theory will be relevant in Saudi Arabia soon (Alajlan & Alreshaidi, 2022). This statement describes how urbanization is one of the reasons behind Saudi Arabia's economic development, supporting the EKC theory premise. As urbanization progresses, the nation is expected to see an increase in environmental deterioration, although it will ultimately develop regulations to mitigate the adverse effects of urbanization. In addition, the Granger causality test shows a positive relationship between economic growth and urbanization (Shahbaz et al., 2014). The results of the Granger causality test provide insight on the relationship between economic growth and urbanization. On the other hand, rural residents are attracted to metropolitan areas due to improved job opportunities and increased earnings resulting from fast economic growth. In addition, the Granger causality test results explain that there is a unidirectional causality relationship from urbanization to energy consumption to economic growth to urbanization (Zhao & Wang, 2015). This implies that there is a unidirectional causal relationship between economic growth, energy consumption, and urbanization. In other words, this unidirectional causality relationship can provide policymakers with a framework for the development of policies that prioritize the management of urbanization and energy consumption in order to accomplish sustainable growth.

2.6 The Nexus of FDI on Economic Growth

Researchers have conducted many studies in the past to investigate the impact of FDI on economic growth. If viewed from the economic perspective, one of which is the lack of capital, where developing countries have many economic problems at the macro level, one way to overcome this problem is foreign direct investment, which prioritizes GDP to attract FDI, which has an impact on triggering environmental degradation in the country. This is supposed to Pata et al. (2022) that developing countries are pollution havens, and foreign direct investment triggers environmental degradation in developing countries worldwide. The statement indicates that energy consumption can cause a short-term economic decline; it is necessary to consider the long-term effects of energy consumption and CO_2 emissions. Therefore, policymakers and relevant stakeholders can adequately consider the potential benefits of reducing renewable energy consumption on economic growth. In conclusion, the energy transition negatively impacts the short term and can result in losses. However, it will positively impact the long-term GDP by proportionally prioritizing the sustainability of economic growth.

On the other hand, in developed countries, foreign direct investment has no influence or does not play an essential role in economic growth (Naveed & Shabbir, 2006). This shows that foreign direct investment in countries does not significantly impact economic growth, meaning that the influx of foreign investment does not contribute to a country's economic growth. This is related to (Nketiah et al., 2020) that foreign direct investment is a factor that can increase economic growth but is not very significant in statistical results.mThis shows that foreign direct investment has a positive impact on economic growth in a country, but not as large as other factors. In addition, although foreign direct investment can contribute to economic growth, foreign direct investment is not the dominant factor that can increase economic growth.

2.7 Previous Research

This study examines the dynamic interrelationships of C02 emissions and Renewable Energy Consumption on Economic growth in G20 Countries. The research approach seeks to assess, including both the short-term and long-term perspectives. In addition, several variables control this research, such as trade openness, urbanization, and foreign direct investment.

Table 2.1: Summary of Literature Review

Author	Variables	Countries	Year	Method	Conclusion
Zhao & Wang, (2015)	Energy Efficiency, Environmental Investment, Environmental performance, Malmquist index, Panel VAR	China	1980–2012	Vector error-correction model (VECM)	❖ This research shows that urbanization and economic growth significantly impact increasing energy consumption in China. Apart from that, there is a need for a policy to prioritize optimizing industrial structures, increasing energy efficiency, and restructuring the energy system to achieve sustainable growth.
Supron & Myszczyszyn, (2023)	Renewable energy, CO2 Emissions, Economic Growth, FMOLS, DOLS, ARDL Panel Data	Visegrad countries (the Czech Republic, Hungary, Poland, and Slovakia).	1991-2021	EKC Hypothesis, FMOLS/DOLS and ARDL approaches,	❖ REC shows that renewable energy consumption positively impacts economic growth in the Visegrad countries (the Czech Republic, Hungary, Poland, and Slovakia). Therefore, it has a particularly positive long-term impact on GDP in Visegrad countries.

					❖ Non-renewable energy consumption significantly impacts GDP, especially in Poland, the Czech Republic, and Slovakia. ❖ CO2 emissions harm economic growth in the Visegrad countries. The causality test revealed a one-way and two-way association between different variables in each country. ❖ To successfully implement a strategy that promotes the use of renewable energy while also ensuring economic growth, it is crucial to identify renewable energy sources that are both effective and efficient.
Saidi & Hammami, (2015)	Energy Consumption, CO2 emissions and Economic growth	58 Countries Selected	1990-2012	Generalized Method of Moments (GMM)	❖ Research shows that, in particular, economic growth, CO2 emissions, and energy consumption complement each other. In addition, economic growth and CO2 emissions have a statistically significant favorable influence on energy consumption in the 58 selected countries.

Yan et al., (2022)	Three-sector model; EKC, G20 nations, curbing CO2 emissions, Economic Growth	G20 Countries	1990-2014	EKC Hypothesis, Environmental IPAT, and STIRPAT model	❖ The research findings show a relationship between GDP, the population of various sectors determining CO2 emissions, and the differences between developing and developed countries. In addition, economic growth can improve the environment, where developed countries demonstrate better energy efficiency and technology to reduce emissions. ❖ Renewable energy negatively impacts CO2 emissions in developing countries in the G20, while industry and consumption of non-renewable energy have a positive relationship with CO2 emissions. This research suggests the importance of increasing productivity and energy efficiency to reduce emissions without fueling economic growth.
Saad et al., (2023)	Environment Kuznet,, Africa Panel cointegration	23 African countries	1980–2019	Pedroni approach to panel cointegration analysis	❖ The study results show that real GDP and energy consumption positively impact CO2 emissions in 23 African countries. However, energy consumption has a

					negligible impact where the evidence supports EKC. In contrast, income increases and CO2 emissions show a decline in most countries.
Alyasari & Alzawbaee, (2020)	Economic growth, Electricity consumption, CO2 Emissions, Panel data	GCC Countries	(1996).-2013	Panel Data Analysis	❖ An increase in carbon dioxide emissions will negatively impact economic growth, whereas energy consumption positively impacts carbon dioxide emissions. In addition, the research underscores the significance of capital formation and exports in the GCC countries' economic growth, as they can help mitigate the adverse effects of CO2 emissions.
Marinaș et al., (2018)	Renewable Energy consumption, Economic Growth	10 European Union (EU) member states from Central and Eastern	1990–2014	Autoregressive Distributed Lag	❖ Studies indicate a direct correlation between long-term economic growth and the use of renewable energy. However, in the short term, there is an inverse causal link and no clear causation between economic growth and renewable energy consumption.

		Europe (CEE)			
Ramadhan et al., (2023)	Carbon dioxide emissions, GDP, GFCF, Urban population, Panel Data	G20 Countries	2000 - 2019	Panel Data Analysis	❖ The gross domestic product, gross fixed capital formation, and urban population all positively and considerably impact the rise in C02 emissions in G20 countries.
Onofrei et al., (2022)	Environmental degradation, CO2 emissions, economic growth, cointegration analysis, climate risk	27 UE Member States	2000 - 2017	Dynamic Ordinary Least Squares (DOLS), unit root tests, and cointegration technique	❖ Research indicates that a change of one percent in GDP results in an increase of 0.072 percent in carbon dioxide emissions; hence, there is a need for a plan that will allow for sustainable economic growth in the 27 member states of the European Union.
Pala, (2020).	Economic Growth, Energy Consumption, Panel Unit-root; Panel Granger Causality, cointegration	G20 Countries	1990-2016	Panel Granger Causality and VECM	❖ This research demonstrates that the relationship between energy consumption and economic growth in G20 countries from 1995 to 2016 is bidirectional, with evidence of a short- and long-term relationship. ❖ This research corroborates the EKC theory, demonstrating a substantial cointegration relationship between the

					labor force, energy use, capital stock formation, and GDP.
Alajlan & Alreshaidi, (2022)	Climate change, Saudi Arabia, Economic Growth, CO2 emissions, Urbanization	Saudi Arabia	1985-2019	ECMs	❖ Based on this study, both in the short and long terms, there is a positive, unidirectional causation from economic growth to CO_2 emissions, and 1% GDP Granger growth specifically resulted in a 0.33% short-term increase in CO_2 emissions and a 0.15% long-term increase. ❖ Furthermore, the analysis revealed that urbanization boosts economic growth, so the Environmental Kuznets Curve (EKC) theory is relevant in Saudi Arabia over the near future.
Mendoza et al., (2021)	CO2 emission, GDP Per Capita, Employment Rate, Energy Consumption, Environmental Kuznets Curve	Japan, China, and Korea	1997-2014	EKC Hypothesis	❖ These results show the complicated link between environmental quality and economic growth, which affects the execution of measures such as the Kyoto Protocol and the Paris Climate Agreement.

					❖ Research shows that Japan has no causal relationship between economic growth and emissions. A positive correlation exists between GDP per capita, employment, and CO2 emissions. ❖ In China, the data indicates a non-positive correlation between GDP per capita and CO2 emissions, while in Korea, the correlation between GDP per capita, energy consumption, and CO2 emissions is positive.
Mardani et al., (2018)	Energy, CO2, growth, adaptive neuro-fuzzy inference system (ANFIS)	G20 Countries	1962-2016	Adaptive Neuro-Fuzzy Inference System (ANFIS) & the Least-Squares Estimate (LSE)	❖ Studies indicate a positive correlation between economic growth and CO2 emissions in G20 countries.
González-Álvarez & Montañés, (2023)	Decoupling, Carbon dioxide emissions, Economic growth, Energy consumption, Structural breaks Great recession	31 Countries	1974 -2017	Bai and Perron's Methodology	❖ Research shows that the more energy consumed, the greater the CO2 emissions produced. Therefore, switching to environmentally friendly energy is necessary.

					❖ Research shows several countries have begun to separate CO2 emissions and economic growth.
Feriansyah et al., (2022)	Economic growth;, GDP, CO2 emission, Panel ARDL	ASEAN Countries	1994-2018	Panel-ARDL (Autoregressive Distributed Lag)	❖ The study findings indicate a substantial long-term correlation between the GDP and CO2 emissions in ASEAN countries. Moreover, the study findings indicate a positive correlation between GDP growth and CO2 emissions, which ultimately reach a peak before declining. This research demonstrates a positive correlation between a 1% rise in GDP and a 0.06173% increase in CO2 emissions.
Khoshnevis Yazdi & Dariani, (2019)	Economic Growth, Energy Consumption, Urbanisation, PMG, Asian countries	Asian Countries	1980-2014	The pooled mean group (P.M.G.) & Environmental IPAT, and STIRPAT model	❖ Research shows a two-way causal relationship between economic growth, urbanization, and CO2 emissions. ❖ In addition, there is a positive relationship between GDP, energy consumption, and urbanization with CO2 emissions. ❖ This strategy should go beyond simply promoting economic growth. It should encompass measures such as reducing

					government intervention in the energy sector, promoting renewable energy sources, and considering energy policy and other social and economic objectives.
Aye & Edoja, (2017)	CO_2 Emission; Economic Growth, Energy Consumption Population, Dynamic Panel Threshold Model, Panel Causality	31 Developing Countries	1940-2004	Dynamic Panel Data Model	❖ Research shows a U-shaped relationship between economic growth and CO_2 emissions in developing countries, where emissions can begin to fall with increases in income and technology, as well as the implications of effective policies. ❖ On the other hand, energy consumption and population significantly impact CO_2 emissions. ❖ Financial growth has positive and negative impacts on CO_2 emissions, depending on the country's level of opinion.
Shahbaz et al., (2020)	Economic Growth, Electricity Consumption, Urbanization	38 REC Countries	1990-2018	DOLS, FMOLS, and heterogeneous non-causality	❖ Research shows renewable energy's significant and positive impact on economic growth. In addition, solar and wind energy (renewable energy investments) are more competitive than

					traditional energy sources and are essential to support sustainable economic growth. ❖ Renewable energy consumption experiences an optimistic or significant impact on economic growth due to different conditions and policies in various countries. In addition, research shows that increasing renewable energy consumption will support sustainable economic growth.
Gillani & Sultana, (2020)	EKC framework, Economic growth, Energy consumption, CO2 emissions, Sustainable economic expansion , ARDL/PMG ASEAN countries	9 ASEAN Countries	1970-2019	ARDL/PMG	❖ Research suggests that there is a positive between the expansion of the economy and the use of energy on the level of carbon dioxide emissions in ASEAN countries. ❖ This result is consistent with the EKC hypothesis, which proposes that a rise in economic growth is associated with increased carbon emissions to a greater extent.

					❖ On the other hand, emissions can decrease even more once a nation achieves a certain wealth level.
Jian et al., (2019)	Financial Development; C02 Emission, Energy Consumption; Economic Growth, VECM model	China	1982-2017	VECM	❖ However, short-term CO2 emissions positively impact energy consumption, economic growth, and financial growth. On the other hand, the research findings indicate a long-term cointegration relationship between energy consumption, economic growth, and financial growth in China from 1982 to 2017.
Magazzino, (2014)	Economic Growth, C02 Emissions, Energy Use, ASEAN, Panel Data	ASEAN Countries	1971-2007	VAR	❖ The research shows that economic growth directly affects six ASEAN countries' CO2 emissions and energy consumption. This study also offers a perspective on the necessity of a more effective and efficient energy policy, as reliance on fossil fuels can lead to energy consumption that causes environmental harm.

Adebayo et al., (2022)	CO2 emissions, Economic growth, Globalization, Technological innovation, Sweden	Sweden	1965-2019	Quantile-on-quantile regression [QQ] Analysis	❖ Empirical data has shown that economic expansion in Sweden generally leads to decreased CO2 emissions across all levels of economic growth and CO2 emission quantiles. ❖ In Sweden, renewable energy has a negative impact on CO2 emissions. Therefore, there is no correlation between REC and CO2 in Sweden.
Pertiwi et al., (2024)	Economic Growth, FDI , industrial value-added, Population, EKC	G20 Countries	2000 - 2022	Panel Data, Environmental Kuznet Curve (EKC)	❖ Panel data analysis conducted for the period 2000–2022 reveals a clear positive relationship between the Gross Domestic Product (GDP) and carbon dioxide (CO2) emissions in G20 countries.

2.8 Research Hypothesis

The study aimed to look into the dynamic interrelationships of C02 emissions and renewable energy consumption on economic growth in G20 countries in the short term and long term. Besides, several variables control this research, such as trade openness, urbanization, and foreign direct investment. In addition, the study hypotheses might be formulated in the following manner, taking into consideration these hypotheses:

H0: There is no correlation between CO2 emissions and economic growth in G20 countries, whether long-term or short-term.
H1: The association between CO2 emission factors and economic growth in G20 countries may be seen over the long and short term.
H0: There is no correlation between REC factors and economic growth in G20 countries, whether in the long-term or short-term
H1: The association between REC factors and economic growth in G20 countries may be seen in the long and short term.

2.7 Research Gap

Recently, several countries have modified their energy policies to include renewable energy sources to ensure sustainable growth in the long run (Niyonzima et al., 2022). The statement emphasizes the increasing acknowledgment of the significance of renewable energy sources in attaining sustainable growth. Thus, it is essential for governments to persistently adapt their energy policies to give precedence to renewable energy sources and guarantee a sustainable future. In addition, we use data from a period of 33 years with a total of 660 observations, where we use one variable, renewable energy consumption, which is still not as widely used as in previous studies (Alajlan & Alreshaidi, 2022; Alyasari & Alzawbaee, 2020; Khoshnevis Yazdi & Shakouri, 2017; Mitić et al., 2022; Vo et al., 2019). Furthermore, Several previous studies have not conducted dynamic interrelationships between CO2 emissions and renewable energy consumption on economic growth in G20 countries. While detailed and specifically about G20 countries and also using the Panel VAR approach, these studies have only focused on a single country or several groups, such as ASEAN countries, GCC countries, EU members, etc(Pala, 2020; Ramadhan et al., 2023; Vo et al., 2019; Zhao & Wang, 2015).

Therefore, we aim to enhance our comprehension of the dynamic interrelationships between CO_2 emissions and renewable energy consumption and their impact on economic growth in G20 countries in the short and long term. Then, the research focuses more on the duration of observation time, variables, data, and the right econometric model to fill this gap and reduce the previously planned results, namely obtaining research results as insight and knowledge for academics and non-academics or related stakeholders. The goal of this study is to provide significant insights into the dynamic connections between carbon dioxide emissions, renewable energy consumption, and economic growth in G20 countries. Besides, the objective of this investigation is to contribute to the ongoing global discourse regarding environmental preservation without reducing economic growth. Furthermore, this research benefits the G20 community, stakeholders, policymakers, and non-governmental organizations.

CHAPTER 3

METHODOLOGY

3.1 Research Design

The main goal of this study is to investigate the dynamic interrelationships of CO2 emissions and renewable energy consumption on economic growth in G20 countries, as well as other control variables such as trade openness, urbanization, and foreign direct investment. In addition, this study employs a quantitative research methodology, sourcing secondary data from World Bank indicators and presenting the findings through the Vector Autoregression (VAR) model.

3.2 Data Collection Methods and Definition of Variables and Model

This research used secondary data over 33 years, from 1990 to 2022. In addition, this study will focus on the G20 countries, which will be the primary subject. In addition, the data for this inquiry was collected via a panel data series collection method. The study focuses on G20 countries, including Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkiye, the UK, the USA, and the EU. To accomplish the study goals, GDP is measured, whereas C02 emissions and renewable energy consumption are independent variables, such as trade openness, urbanization, and foreign direct investment. as control variables. It can be seen in Table 3.1 below:

Table 3.1

Variables Definition

No	Variable	Description	Units	Sources	References
1	*Dependent Variable* GDP	C02 Emissions Gross Domestic Product Per Capita	Current US$	WDI from The World Bank, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD	(Feriansyah et al., 2022a; Supron & Myszczyszyn, 2023)
2	*Independent Variable* C02	C02 Emissions	Metric tons per capita	WDI from The World Bank	(Feriansyah et al., 2022b; Supron &

				https://data.worldbank.org/indicator/EN.ATM.CO2E.PC	Myszczyszyn, 2023)
3	*Independent Variable* REC	Renewable Energy Consumption	Annual %	WDI, from The World Bank https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS	(Supron & Myszczyszyn, 2023)
4	*Control Variables* TO	Trade Openness	Annual %	WDI, from The World Bank https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS	(Adebayo et al., 2022)
6	*Control Variables* URB	Urban Population	Annual %	WDI, from The World Bank https://data.worldbank.org/indicator/SP.POP.TOTL	(Khoshnevis Yazdi & Shakouri, 2017; Shahbaz et al., 2014)
7	*Control Variables* FDI	Foreign Direct Investment	Annual %	WDI, from The World Bank https://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD	(Pata et al., 2022)

Sources: World Bank Indicators, 2024

The independent variables are succinctly described as follows:

GDP Growth (Current US$) as Dependent Variable: The GDP per capita determines this index's performance from year to year. If CO2 emissions rise, it is due to increased urbanization and industrial activity in the country. These variables have been included in the previous research by (Feriansyah et al., 2022b; Suproń & Myszczyszyn, 2023)

C02 Emissions (Metric Tons) as Independent Variable: It measures the investments of several related parties regarding business and assets, such as investors, governments, and other associated parties. This can include investment in various sectors of the country. These variables have been included in the previous research by (Feriansyah et al., 2022a; Supроń & Myszczyszyn, 2023)

REC (Annual %) as Independent Variable: REC (%): Renewable Energy Consumption pertains to using energy derived from sustainable sources that can be renewed naturally, including solar, wind, hydro, geothermal, biomass, and tidal energy. Unlike fossil fuels, renewable energy sources are sustainable and do not decline over time. They can supply the world's growing energy needs without exhausting natural resources. This analysis expects a negative association since increasing REC will reduce CO2 emissions(Suproń & Myszczyszyn, 2023).

Trade openness (Annual %) as Control Variable: Trade openness quantifies the degree to which a nation participates in international trade with its GDP. This variable has also been used in previous literature by (Adebayo et al., 2022)

Urbanization (%) Control Variable: Urbanization is a dynamic moderation phenomenon in which social and economic capabilities from rural areas move to urban areas. In addition, high population increases can increase C02 emissions(Khoshnevis et al., 2019). This variable has also been used in previous literature by(Shahbaz et al., 2014)

Foreign Direct Investment (%) Control Variable: It measures the amount of carbon dioxide gas released into the atmosphere by all forms of human activity, such as burning fossil fuels and other industrial processes in the country. This variable has also been used in previous literature by (Pata et al., 2022)

Control Variables

Based on the literature above, this study used three control variables: trade openness, urbanization, and foreign direct investment. First, we use a yearly proxy for trade openness as a metric to gauge a country's level of international trade engagement. It represents the annual increase in the value of a country's trade volume, typically calculated as the sum of imports and exports. Second, we express a proxy for urbanization as an annual percentage, while a population growth rate indicator uses statistics to measure a municipality's yearly population growth rate. Thirdly, we express a proxy for foreign direct investment as the annual percentage of a person, corporation, or government's investment in a business or asset located in a foreign country or the world and all control variables provided by World Bank indicators.

3.3 VAR Analysis

3.3.1 Introduction

The Panel Vector Autoregression (PVAR) model can use panel data to incorporate spatial dimensions and address individual heterogeneity (Yang et al., 2023). In addition, the PVAR model combines the advantages of panel data and better serves research needs by allowing more observed sample values. Then, by extending its time series to the spatial direction, the PVAR model can theoretically address individual heterogeneity using panel data. In addition, the text and equation presented explain a Panel Vector Autoregressive (Panel VAR) model, a widely used econometric approach for analyzing the dynamic interrelationships among several time series variables across distinct entities. The panel VAR model is shown in its general form. The following system of linear equations defines the model (Abrigo & Love, 2016):

$$Y_{it} = Y_{it-1}A_1 + Y_{it-2}A_2 + \dots\dots + Y_{it-p+1}A_{p-1} + Y_{it-P}\,A_p + X_{it}B + u_i + e_{it}$$
$$i \in \{1,2 \dots\dots, N\}, t \in \{1,2 \dots\dots, T_1\}$$

Where Y_{it} is a (1x k) as vector of dependent variables, X_{it} is a ((1x l) vector of exogenous covarietes, and also u_i and e_{it} are (1x k) vector of dependent variable-specific panel fixed effects and indiosyncratic erros, respectively. In addition, The (k x k) is a metric $A_1, A_{2,\dots\dots\dots\dots,}A_{p-1,}A_p$ and the (l x k) matric **B** are parameters be to be estimated. Aside from that, we contend that innovations are characterized by the following qualities: **E**(e_{it}) = 0, **E** (è$_{it}$ e_{it}) = ∑, and **E** ((è$_{it}$ e_{is}) = 0 for all t > s.

In the next step, we will examine the analysis diagram that determines the suitability of the data for the VAR or VECM model. Besides this process consists of several steps, including testing stationarity and cointegration and selecting a panel data model to improve the analysis's strength. Furthermore, we will examine the analysis diagram that determines the suitability of the data for the VAR or VECM model. This process consists of several steps, including testing stationarity and cointegration and selecting a time series model to improve the analysis's strength. This is illustrated in Figure 3.1 below:

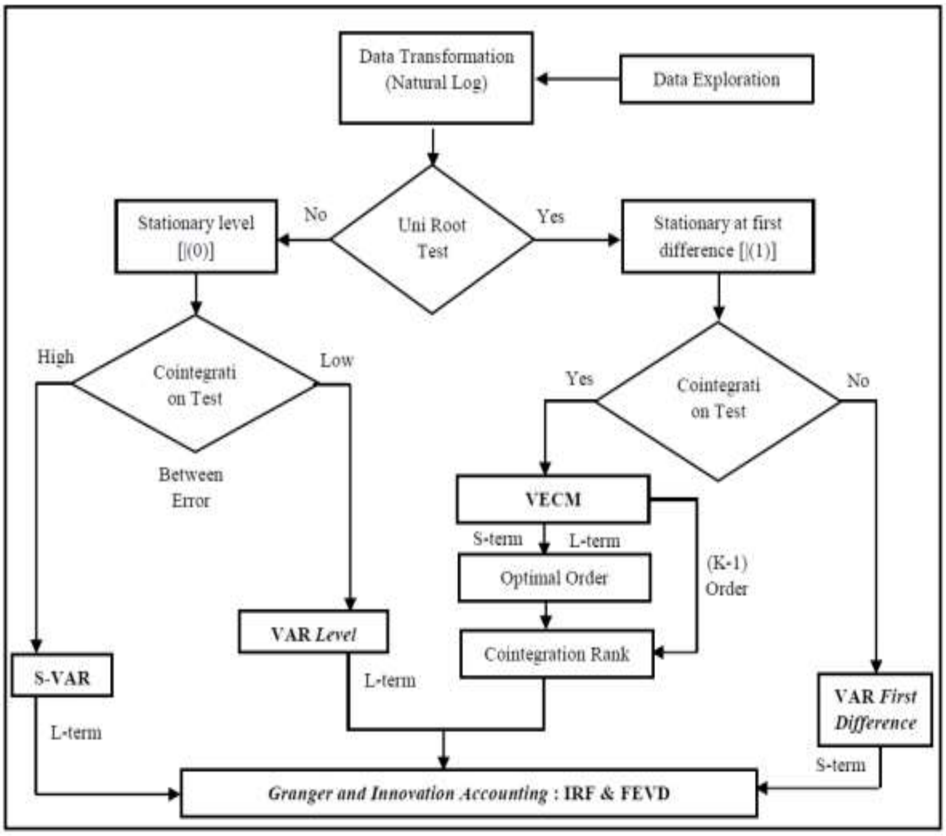


Figure 3.1 : VAR & VECM Model

Sources: (Gujarati & Porter, 2009)

Figure 1 shows the methodological steps that must be taken to conduct time series analysis using vector autoregression (VAR) and vector error correction model (VECM). In addition, data exploration and transformation were carried out, where the data was transformed using natural logarithms to stabilise variance and normalise the data distribution. Then, the unit root test is used in the unit root test stage by employing several methods, namely Levin, Lin & ChuFisher, Augmented Dickey Fuller-Fisher, and Philips Perron-Fisher, to determine the stationarity of the series at the level or first difference, where this unit root test is essential to obtain accurate time series modelling. In addition, if the data results are stationary at the level, a cointegration test can be performed to assess whether there is a long-term equilibrium relationship between variables. Based on the level of cointegration, the analysis can be continued with the structural VAR model for highly cointegrated series or the VAR model at the lowest level. If the data is not stationary at the level, we will do a cointegration test to determine whether the value is below 0.005 using the VECM model and whether the p-value is above 0.005 for the VAR model (Gujarati & Porter, 2009). Then, if the VAR model is selected, it can be used to capture short-term and long-term dynamics. The final stage will be carried out by testing Granger causality and innovation accounting, including Impulse Response Function (IRF) and Forecast Error Variance Decomposition (FEVD), to determine the causality and impact of one variable on another.

3.3.2 Model Description

In this part, we carry out different steps of the methodology in the research, which intends to investigate the dynamic link between carbon dioxide emissions and the use of renewable energy in G20 countries on economic growth. This study uses the Panel VAR methodology to investigate the dynamic interrelationships of CO2 emissions and renewable energy consumption on short- and long-term economic growth in G20 countries. Additionally, this approach influences all variables in the cross-sectional time series, incorporates spatial dimensions, and addresses individual heterogeneity through panel data (Zhang et al., 2015).

In a VAR system, all variables are often considered endogenous, with limitations on the indices that may explain the effects of exogenous shocks on the system using theoretical models or statistical data (Abrigo & Love, 2016). Consequently, we have included the VAR specifications for each variable below, which will serve as the foundation for the subsequent analysis (Adebayo et al., 2022; Feriansyah et al., 2022b; Pata et al., 2022; Shahbaz et al., 2014; Supron & Myszczyszyn, 2023; Zhang et al., 2015)

$$logGDP_{it} = \alpha_1 + \sum_{k=1}^{p} \beta_{11} logGDP_{i,t-k} + \sum_{k=1}^{p} \beta_{12} CO2_{i,t-k} + \sum_{k=1}^{p} \beta_{13} REC_{i,t-k} + \sum_{k=1}^{p} \beta_{14} TO_{i,t-k} + \sum_{k=1}^{p} \beta_{15} URB_{i,t-k} + \sum_{k=1}^{p} \beta_{16} FDI_{i,t-k} + \varepsilon_{1it} \text{......................(Equ 3.1)}$$

$$logC02_{it} = \alpha_2 + \sum_{k=1}^{p} \beta_{11} logGDP_{i,t-k} + \sum_{k=1}^{p} \beta_{12} CO2_{i,t-k} + \sum_{k=1}^{p} \beta_{13} REC_{i,t-k} + \sum_{k=1}^{p} \beta_{14} TO_{i,t-k} + \sum_{k=1}^{p} \beta_{15} URB_{i,t-k} + \sum_{k=1}^{p} \beta_{16} FDI_{i,t-k} + \varepsilon_{2it} \text{......................(Equ 3.2)}$$

$REC_{it} = \alpha_3 + \sum_{k=1}^{p} \beta_{11} logGDP_{i,t-k} + \sum_{k=1}^{p} \beta_{12} CO2_{i,t-k} + \sum_{k=1}^{p} \beta_{13} REC_{i,t-k} + \sum_{k=1}^{p} \beta_{14} TO_{i,t-k} + \sum_{k=1}^{p} \beta_{15} URB_{i,t-k} + \sum_{k=1}^{p} \beta_{16} FDI_{i,t-k} + \varepsilon_{3it}$…………………(Equ 3.3)

$TO_{it} = \alpha_4 + \sum_{k=1}^{p} \beta_{11} logGDP_{i,t-k} + \sum_{k=1}^{p} \beta_{12} CO2_{i,t-k} + \sum_{k=1}^{p} \beta_{13} REC_{i,t-k} + \sum_{k=1}^{p} \beta_{14} TO_{i,t-k} + \sum_{k=1}^{p} \beta_{15} URB_{i,t-k} + \sum_{k=1}^{p} \beta_{16} FDI_{i,t-k} + \varepsilon_{4it}$…………………(Equ 3.4)

$URB_{it} = \alpha_5 + \sum_{k=1}^{p} \beta_{11} logGDP_{i,t-k} + \sum_{k=1}^{p} \beta_{12} CO2_{i,t-k} + \sum_{k=1}^{p} \beta_{13} REC_{i,t-k} + \sum_{k=1}^{p} \beta_{14} TO_{i,t-k} + \sum_{k=1}^{p} \beta_{15} URB_{i,t-k} + \sum_{k=1}^{p} \beta_{16} FDI_{i,t-k} + \varepsilon_{5it}$…………………(Equ 3.5)

$FDI_{it} = \alpha_6 + \sum_{k=1}^{p} \beta_{11} logGDP_{i,t-k} + \sum_{k=1}^{p} \beta_{12} CO2_{i,t-k} + \sum_{k=1}^{p} \beta_{13} REC_{i,t-k} + \sum_{k=1}^{p} \beta_{14} TO_{i,t-k} + \sum_{k=1}^{p} \beta_{15} URB_{i,t-k} + \sum_{k=1}^{p} \beta_{16} FDI_{i,t-k} + \varepsilon_{6it}$…………………(Equ 3.6)

Description Equation :

LogGDP: Log of GDP

LogC02 = Log of C02

REC = Renewable Energy Consumption (Annual %)

TO = Trade Openness (Annual %)

URB = Urban Population (Annual %)

FDI = Foreign Direct Investment (Annual %)

Here, $logGDP_{it}, logC02_{it}, REC_{it}, TO_{it}, URB_{it}, FDI_{it}$ are the world bank indicators estimated Economic Growth, Carbon Emissions, Renewable Energy Consumption, Trade Openesss, Urbanization, and Foreign Direct Investment. In addition, The subscript $t - k$ denotes that these values are lagged, with k ranging from 1 to p, the maximum latency length that is considered. On the other hand, α_1, $\alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6$ are the intercepts of the respective equations, and then β_{11}, $\beta_{12}, \beta_{13}, \beta_{14}, \beta_{15,}\beta_{16}$ are the coefficient that corresponds to the lagged variables, which illustrates the influence of each lagged variable on the dependent variables. In addition, ε_{1it}, $\varepsilon_{2it}, \varepsilon_{3it}, \varepsilon_{4it}, \varepsilon_{5it}, \varepsilon_{6it}$ are the error elements, which represent the impact of unobserved factors or disturbances on each individual equation. Several variables in the model above, such as GDP and CO2 emissions, are logarithmic, as Wooldridge (2016) explained, that practical data transformation approach in statistics to help achieve goals such as normalizing data distribution, facilitating interpretation, and reducing the impact of outliers.

3.3.3 Stationary Test

Stationarity testing is a crucial step in time series analysis to verify the accuracy of econometric models such as Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) are used to ascertain data stationarity (Gujarati & Porter, 2009). This section discusses using the well-known econometric program EViews 13 from World Bank Indicators for time series and cross-section data analysis. Therefore, when estimating the Panel Vector Autoregression (PVAR) model, we should determine the first level, first difference, and shape of the error correction vector based on the time series properties of the endogenous variables considered in the analysis. As a result, analyzing the time series properties of the endogenous variables is a critical first step.

Then, if the panel data has a unit root, we can say that the data moves randomly. If the absolute statistics show results greater than the critical value, this indicates that the panel data is either stationary or rejects the null hypothesis. In this study, the panel data unit root tests method is the Levin, Lin & Chu t-test, ADF (Augmented Dickey-Fuller)-Fisher test and Philips-Perron (PP)-Fisher test. Levin, Lin & Chu (Baltagi, 2005).

3.3.4 Model Selection: Determine Lag Length Optimal

The first stage of VAR analysis is the selection of the most suitable lag length, which utilizes the preceding lag length as a model for forecasting future values (Gujarati & Porter, 2009). Besides, the ideal lag duration is determined with the goal of preventing both overfitting and underfitting. The standard approach to determine the most suitable lag duration usually involves using information criteria such as the Akaike Information Criterion and the Bayesian Information Criterion. In the context of VAR (Vector Autoregression) analysis, the initial stage is to determine the most suitable lag length. This involves utilizing the preceding lag length as a model to predict future values. This phase is essential because it establishes the duration of historical data that is employed to forecast future values. In order to prevent overfitting and underfitting, the optimal latency length is established.

When a model is excessively intricate and overfits the noise in the data, it can lead to subpar performance on new, unseen data. This phenomenon is known as overfitting. In contrast, underfitting is the phenomenon of a model that is overly simplistic and fails to identify significant patterns in the data, resulting in inaccurate predictions. Two frequently employed information criteria for determining the optimal latency length are the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). To determine the ideal lag duration, a recommended approach is to minimize the Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), or Bayesian Information Criterion (BIC) for each lag length using a trial-and-error process. The formula for the Akaike Information Criterion (AIC), which is a widely used test, is as follows (Mendoza et al., 2021):

$$In\ AIC = (2k/n) = In\ (RSS/n)$$

The variable k represents the number of regressors, which includes the intercept. The variable n represents the number of observations. RSS stands for the regression sum of squares. By doing experiments with a suitable number of lags in the model, the lag length that yields the lowest AIC value would represent the most acceptable or optimum lag length.

Researchers can assess various latency lengths and select the one that most effectively balances complexity and suitability by employing these criteria. Researchers can compare and select the most suitable latency length by utilizing the AIC and BIC, which offer quantitative measures of the relative quality of each model. In summary, the selection of the most suitable latency length is a critical stage in VAR analysis, as it determines the duration of historical data that is used to predict future values. By employing information criteria such as AIC and BIC, researchers can prevent overfitting and underfitting by determining the optimal latency length that strikes a balance between appropriateness and complexity. This enables the development of more precise predictions and a more comprehensive comprehension of the fundamental relationships between variables within a system..

3.3.5 Granger Causality Test

The Granger Causality Test is a technique to determine whether one time series can be used to predict another time series (Wooldridge, 2016). In addition, this test is based on the concept that if variable X Granger causes variable Y, it indicates the existence of values in the past, thus providing useful information to predict Y in the future, beyond the information on Y itself. In other words, it investigates whether the values of one variable (X) contain information that is useful for predicting the values of another variable (Y) beyond what can be derived from Y itself. The test is predicated on the idea that the past values of variable X provide valuable information that can be used to predict the future values of variable Y if variable X Granger causes variable Y. The test is predicated on the notion that the prognostic capabilities of a regression model for Y should be enhanced by the incorporation of lagged values of X if X Granger causes Y.

The examination comprises numerous procedures. A regression model is initially estimated for Y by utilizing the lagged values of X and Y's own values. Then, a second regression model is estimated for Y using its own lagged values and the lagged values of X, with X's lagged values being excluded. If the model's forecasting capabilities are enhanced by the inclusion of X's lagged values, it implies that X Granger is the cause of Y. In contrast, the absence of an improvement in the model's forecasting capabilities as a result of the incorporation of X's lagged values implies that X does not Granger cause Y. In summary, the Granger Causality Test is a valuable instrument for determining the direction of causality between two or more variables in a time series analysis. It offers a statistical approach for determining whether one variable can be employed to predict another variable above and beyond the information that can be derived from the variable itself.

3.3.6 Impulse Response

Impulse Response Function is a method of describing the variables in the model that are in response to an abrupt or "shock" in the other variables (Lütkepohl, 2005). In addition, IRF is highly beneficial for the analysis of VAR (Vector Autoregression) or the dynamics of the relationship between variables in the short and long term. IRF demonstrates the extent and duration of the shock's impact on other variables when one variable is impacted. Conversely, this data is crucial for legislators as it enables them to make wise judgments, predict and react to any economic upheavals. Apart from that, the IRF may be used to investigate other economic events, including the impact of variations in monetary policy on unemployment rates, GDP development, and inflation. For example, policymakers can ascertain the short- and long-term impacts on inflation, interest rates, and economic activity by examining the IRF of a monetary policy disruption. In summary, the Impulse Response

Function is a valuable instrument for the analysis of the dynamic relationships between variables in a VAR model. Researchers and policymakers can acquire a deeper understanding of the causal relationships between variables and the propagation of disturbances through the system by analyzing the IRF. The Granger causality test can only elucidate the direction of the causal relationship between variables (Mitić et al., 2022). This remark indicates that the Granger causality test alone examines the direction of the causal link between two variables. Furthermore, the Granger causality test does not provide information on the intensity or degree of the link but rather elucidates whether another causally influences one variable. Hence, it is essential to take into account the implications of the Granger causality test findings when evaluating them since they provide insights into the connection between variables. In addition, impulse response analysis is simply understood as unstable changes in variables in response to some internal shocks (Zhao & Wang, 2015).

3.3.7 Variance Decomposition

One method in VAR analysis is variance decomposition, which is one technique for determining the proportion of variation in the prediction error of a particular variable attributed to unexpected changes in other variables in the VAR analysis (Gujarati & Porter, 2009; Wooldridge, 2016). In addition, it illustrates the need for a more comprehensive understanding of the extent to which external forces can influence the internal variables in the model.

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter will explain the result and discuss the method for presenting the findings from the Vector Autoregression (VAR) model, which examines the dynamic relationship between C02 emissions and renewable energy consumption in G20 countries and its influence on economic growth. This research approach aims to evaluate short-term and long-term perspectives. Various variables, such as trade openness, urbanization, and foreign direct investment, also influence this study. Moreover, this chapter provides a comprehensive overview of the tests that we will conduct. These include descriptive statistics, correlation matrix, unit root analysis, VAR lag order selection criteria, cointegration test, causality analysis using a VAR, VAR estimation, Granger causality, impulse response function analysis, and variance decomposition analysis. Next, we will present the results and discuss the analysis's findings, highlighting their mutual significance. Ultimately, this chapter will conclude by explaining the significance of the VAR analysis's findings and outlining the necessary actions for the government, regulatory bodies, companies, industries, policymakers, environmental activists, NGOs, civil society, academics, and researchers about environmental concerns and economic growth, particularly in the G20 countries.

4.1 Result

4.1.2 Descriptive Statistics

This section shows the results of descriptive statistics consisting of several main menus from the data set, such as maximum value, minimum value, mean, median, standard deviation, skewness, kurtosis, etc (Adebayo et al., 2022; Pertiwi et al., 2024). In addition,

Table 4.1: *Descriptive Summary of Statistics*

	GDP (US$ Current)	C02 (Metric Tons)	REC (Annual %)	TO (Annual %)	URB (Annual %)	FDI (Annual %)
Mean	20248.71	7.997175	14.52913	49.81918	71.84829	1.968925
Median	15844.63	7.491583	9.780000	49.36433	76.87900	1.613738
Maximum	76329.58	20.46980	59.18000	110.5771	92.34700	12.73150
Minimum	301.5008	0.647451	0.010000	13.75305	25.54700	-3.606928

Std. Dev.	16746.16	5.084335	13.82813	19.10887	15.73595	1.821554
Skewness	0.684655	0.561330	1.372940	0.368552	-1.469760	1.772771
Kurtosis	2.503062	2.410995	3.947050	2.822823	4.461099	8.926312
Jarque-Bera	58.35378	44.20050	232.0109	15.80465	296.3286	1311.531
Probability	0.000000	0.000000	0.000000	0.000370	0.000000	0.000000
Sum	13364150	5278.135	9589.223	32880.66	47419.87	1299.490
Sum Sq. Dev.	18480584	17035.46	126012.2	240633.1	163181.6	2186.600
Observations	660	660	660	660	660	660

Source: *Author's Computation in Eviews 13*

In the descriptive statistics table 4.1 above, there are six variables: GDP as a dependent variable, CO2 emissions as an independent variable, renewable energy consumption as an independent variable, and three control variables: trade openness, urbanization, and foreign direct investment. Additionally, we present all the above variables in their original form without altering the logarithm of variables with different values, like GDP and CO2 emissions, by leveraging insights into the distribution and characteristics of 660 observations.

Table 4.1 shows that the highest value of GDP is US$76,239.58, and the lowest is US$301.50. In addition, the average value across all GDP data sets is US$20,248.71 with a median value of US$15,844.63, the positive Skewness value is 0.684655, and the quotient is 2.503062, which shows that the GDP value is very high, resulting in differences from G20 member countries. The high Jarque-Bera Statistics value and low probability indicate abnormality and economic unrest in the G20 countries, highlighting the need for a policy to reduce inequality and promote economic growth. Furthermore, the highest value of C02 is 20.46980 metric per ton, and the lowest value is 0.6471451 metric per ton, with an average value of 7.997175 metric per ton and a median value of 7.491583 metric per ton. In addition, the positive skewness value is 0.561330, and the positive kurtosis value is 2.410955, which shows that the distribution is skewed to the right. In conclusion, C02 emissions vary widely, which shows the various levels of industrialization and environmental policies by G20 countries and their ability to carry out effective and efficient strategies to maintain the GDP balance.

Next, we look at descriptive statistics about REC, which ranges from the highest value of 59.1800% to the lowest value of 0.010000%. The average REC is 14.52913%, while the median is 9.780000%. On the other hand, the positive skewness value of 1.372940 and the curricular value of 3.947050 suggest that several G20 members have utilized a significant amount of renewable energy, despite the wide variation in renewable energy consumption across G20 countries. Then, trade openness has a maximum value of 110.5771% and a minimum value of 13.75305%, with an average value of 49.81918% and a median value of 49.36433%. In addition, the urbanization rate has an average value of 71.84829% and a median of 76.87900%; the maximum value of urbanization is 92.34700%, and the lowest value is 25.54700%. Furthermore, the maximum value of foreign direct investment is 12.73150%, the minimum foreign direct investment is 3.606928%, and the average value of FDI is 1.968925%, with a median value of 1.617338%. In addition, the skewness value of 1.772771 and the kurtosis of 8.926312 indicate that some G20 countries experience much higher foreign direct investment flows than other G20 countries.

4.1.2 Correlation Matrix

Table 4.2: Correlation Matrix

	GDP	C02	REC	TO	URB	FDI
GDP	1.000000					
C02	0.597875	1.000000				
REC	-0.400634	-0.584341	1.000000			
TO	0.157682	0.152377	-0.244387	1.000000		
URB	0.527459	0.493778	-0.590097	0.080786	1.000000	
FDI	0.106194	0.049251	0.006137	0.166975	0.084849	1.000000

Source: *Author's Computation in Eviews 13*

Table 4.12 shows the correlation matrix between GDP, CO2, REC, TO, URB, and FDI variables. In addition, the distance between the correlation coefficient table can be obtained from the numbers -1 and 1. If the coefficient value of 1 indicates a perfect positive relationship, the coefficient -1 indicates a perfect negative relationship and the coefficient 0 means there is no relationship between the variables GDP, CO2, REC, TO, URB, and FDI. Then, the correlation matrix shows the pairwise correlation between the variables. According to the coefficient, it shows that GDP and CO2 have a coefficient value of 0.597875, which indicates a positive relationship, meaning that if GDP increases indirectly, CO_2 emissions also increase, which can indicate that GDP is related to high CO_2 emissions. In addition, the coefficient value of GDP and REC is -0.400634, which indicates a negative relationship between GDP and REC and that high GDP is associated with lower REC. Then, the GDP and TO coefficient value of 0.157682 indicates a weak positive relationship; there is a positive relationship between GDP and TO. Next, GDP and URB have a coefficient value of 0.527459, which indicates a positive relationship, indicating that an increase in GDP will also increase URB. Then, the correlation between GDP and FDI shows a coefficient value of 0.106194, which shows a positive but weak relationship between GDP and FDI. Then, C02 and REC have a coefficient value of -0.584341, indicating a negative relationship where higher C02 emissions are associated with low REC consumption. In addition, the REC and TO coefficient values are -0.244387, indicating a weak negative relationship and that high REC consumption is associated with low TO. Furthermore, the relationship between TO and URB shows a positive and weak relationship, and the correlation of URB and PMA of 0.084849 indicates a positive and weak relationship.

4.1.3 Unit Root Analysis

The unit root test stage determines the stationary or non-stationary nature of the panel data. In addition, stationary data tends to point to the average value and change in the area of the average value. Furthermore, panel data sets can capture differences across individual and cross-sectional units, such as countries, regions, states, consumers, and individuals (Alyasari & Alzawbaee, 2020). The unit root test stage determines whether the panel data is stationary or not. Additionally, stationary data typically results in an average value that fluctuates within the average value area. Furthermore, we conduct the stationary test stage to determine if a unit root exists between the variables, thereby confirming the validity of the relationship. Then, if the panel data has a unit root, we can say that the data moves randomly. If the absolute statistics show results greater than the critical value, this indicates that the panel data is either stationary or rejects the null hypothesis. In this study, the panel data unit root tests method is the Levin, Lin & Chu t-test, ADF (Augmented Dickey-Fuller)-Fisher test and Philips-Perron (PP)-Fisher test. Levin, Lin & Chu(Baltagi, 2005).

Table 4.3: Unit Root Test Results by Levin, Lin, Chu (LLC) Test

At level

Test Types		**LogGDP**	**LogC02**	**REC**	**TO**	**URB**	**FDI**
C	t-Statistic	-1.32328	-3.48356	-2.41274	-0.75137	-3.63777	-4.73921
	Prob	(0.0929)	(0.0002)***	(0.0079)	(0.2262)	(0.0001)***	(0.0000)***
CT	t-Statistic	27.0803	3.03933	6.29011	-3.61777	-3.71834	-4.59515
	Prob	(0.9408)	(0.9988)	(1.0000)	(0.0001)***	(0.0001)***	(0.0000)***

First Difference

Test Types		LogGDP	LogC02	REC	TO	URB	FDI
C	t-Statistic	-12.3140	-6.48463	-5.27667	-15.7141	-19.4963	-12.5455
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
CT	t-Statistic	-10.3605	-4.63727	-3.09542	-13.4165	-50.6596	-9.63102
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Source: Author's computation; **Notes:** *(*) Significant at 1%; (**) Significant at 5%; (***) Significant at 10% and (no) Not Significant.*
Source: *Author's Computation.*

Table 4.4: Unit Root Test Results by Augmented Dickey-Fuller (ADF)

At level

Test Types		LogGDP	LogC02	REC	TO	URB	FDI
C	t-Statistic	25.5225	53.8997	47.3256	41.7573	66.2727	103.605
	Prob	(0.9635)	(0.0699)	(0.1984)	(0.3943)	(0.0056)	(0.0000)***
CT	t-Statistic	31.0723	33.1197	28.2962	112.436	269.525	81.9453
	Prob	(0.8432)	(0.7711)	(0.9173)	(0.0000)***	(0.0000)***	(0.0001)***

First Difference

Test Types		LogGDP	LogC02	REC	TO	URB	FDI
C	t-Statistic	221.840	148.081	163.554	271.069	46.9755	334.988
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.2083)	(0.0000)***
CT	t-Statistic	162.889	114.905	133.154	445.586	289.251	274.364
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Source: Author's computation; ***Notes:*** *(*) Significant at 1%; (**) Significant at 5%; (***) Significant at 10% and (no) Not Significant.*
Source: *Author's Computation.*

Table 4.5: Unit Root Test Results by Phillips-Perron (PP) Test

At level

Test Types		LogGDP	LogC02	REC	TO	URB	FDI
C	t-Statistic	28.3545	61.6151	52.4987	37.7935	164.931	142.318
	Prob	(0.9160)	(0.0156)	(0.0891)	(0.5700)	(0.0000)***	(0.0000)***
CT	t-Statistic	27.0803	24.7805	32.5174	66.0601	309.642	126.900
	Prob	(0.9408)	(0.9717)	(0.7937)	(0.0059)	(0.0000)***	(0.0000)***

First Difference

Test Types		LogGDP	LogC02	REC	TO	URB	FDI
C	t-Statistic	311.753	405.745	422.716	382.745	78.0900	543.659

	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0003)***	(0.0000)***
CT	t-Statistic	295.160	423.513	718.442	448.692	523.321	2519.33
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Source: Author's computation; ***Notes:*** *(*) Significant at 1%; (**) Significant at 5%; (***) Significant at 10% and (no) Not Significant.*
Source: *Author's Computation.*

Tables 4.3, 4.4, and 4.5 summarize the outcomes of the LLC, ADF, and PP tests, which are used to assess stationarity at either the level, first difference, or second difference. The Panel VAR analysis also initiates these three tests to determine the data's stationarity in the first difference. Subsequently, it presents the outcomes of the LLC, ADF, and PP tests in two scenarios, one at the level and the other at the first difference. Therefore, we can declare the data to pass the stationarity test when the test statistic is smaller than the p-value. Furthermore, the results of the Levin, Lin, Chu (LLC) Test show that the data is not stationary at the first level, so it is necessary to test again at the first difference, and the first difference level, the data shows stationarity. Then, the Augmented Dickey-Fuller (ADF) test shows that the data is not stationary at the level and stationary at the first difference, and it is the same in the Phillips-Perron (PP) test, where the data can be stationary at the first difference level. Therefore, all variables must be added "d" to the estimation model in the VAR model test because the new data is stationary at the first difference level

4.1.4 Model Selection: Determine Lag Length Optimally

The first stage of VAR analysis is the selection of the most suitable lag leghth, which utilizes the preceding lag length as a model for forcasting future value (Gujarati & Porter, 2009). Besides, the ideal lag duration is determined with the goal of preventing both overfittin and underfitting. The standard approach to determine the most suitable la duration usually invovles using information criteria as the Akakike Information Criterion and the Bayesian Information.

Table 4.6: *Lag Order Criteria Test Results for VAR Model*

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-2520.70526570187	NA	0.000669	9.718097	9.767180	9.737325
1	-1645.497438056501	1726.852	2.65e-05	6.490375	6.833953*	6.624968
2	-1576.429875621798	134.6817	2.34e-05*	6.363192*	7.001266	6.613150*
3	-1556.812833428653	37.80053	2.49e-05	6.426203	7.358773	6.791527
4	-1540.580160073964	30.90451	2.69e-05	6.502231	7.729297	6.982920
5	-1507.937476389983	61.39336*	2.72e-05	6.515144	8.036706	7.111198
6	-1482.632878260947	47.00816	2.84e-05	6.556280	8.372338	7.267700

Note: ** indicates lag order selected by the criterion: LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion*
Source: *Author's Computation*

Furthermore, the lagged selection criteria test for the VAR model can be seen from the AIC results, and it is concluded that lag 2 is the most optimal lagged from the AIC results (Gujarati & Porter, 2009), and then based on the table, lag 2 is considered the most optimal choice that can be used in the research model

4.1.5 Cointegration Test

In econometrics, the cointegration test is one way to determine the long-run balanced relationship between two or more time series that are not stationary. Furthermore, if the time series are not jointly stationary in the long run then they can be said to be cointegrated (Gujarati & Porter, 2009; Osobajo et al., 2020; Wooldridge, 2016). In short, the cointegration test is a very important tool in identifying how the long-run relationship between non-stationary time series, which determines whether all variables are cointegrated or not.

***Table 4.7: Cointegration Test** Result*

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob	Fisher Stat.* (frm max-eigen test)	Prob.
None	572.2	0.0000	320.4	0.0000
At most 1	276.0	0.0000	138.9	0.0000
At most 2	163.9	0.0000	90.70	0.0000
At most 3	100.5	0.0000	54.61	0.0616
At most 4	78.47	0.0000	56.30	0.0452
At most 5	85.76	0.0000	85.76	0.0000

***Note:** Trace test indicates 6 cointegrating eqn(s) at the 0.05 level, * denotes rejection of the hypothesis at the 0.05 level*
***MacKinnon-Haug-Michelis (1999) p-values*

***Source:** Author's Computation.*

The results of Table 4.1.6 indicate that the cointegration test fails to yield a p-value for all variables below 0.05. Therefore, this study will employ the p-valued statistical model, the Vector Autoregression (VAR) model (Gujarati & Porter, 2009). The cointegration test is unable to produce a p-value below 0.05 for all variables, as evidenced by the results of the table. In addition, this indicates that there is no statistically significant evidence of a long-run equilibrium relationship between the variables studied. However, the results of the cointegration test show that if the p value is less than 0.05, we should reject the null hypothesis, which explains that there is no cointegration where the variables move together over time. However, the above results indicate that we cannot reject the null hypothesis because one variable, trade openness (0.0616), has a p value above 0.05, indicating the absence of cointegration across all variables. Furthermore, the cointegration test results in this study chose the vector autoregression (VAR) model.

4.1.6 Causality Analysis Using a VAR

The granger causality test is a statistical technique that is implemented to evaluate the predictive ability of a specific time series with respect to another time series (Osobajo et al., 2020; Ouzillou et al., 2024). We applied the Granger causality test to all variables in this case, including LogGDP (economic growth), LogC02 (carbon emissions), REC (renewable energy consumption) (annual%), TO = Trade Openness (Annual%), URB (Urban Population) (Annual%) and FDI = Foreign Direct Investment (Annual%) Table 4.1.8 presents the results of the Granger causality test.

Table 4.8: *Granger Causality Test Result*

Null Hypothesis:	Obs	F-Statistic	Prob.
LOG_C02 does not Granger Cause LOG_GDP	620	3.01639	0.0497*
LOG_GDP does not Granger Cause LOG_C02		3.19169	0.0418*
REC does not Granger Cause LOG_GDP	620	2.03686	0.1313
LOG_GDP does not Granger Cause REC		1.28536	0.2773
TO does not Granger Cause LOG_GDP	620	1.51237	0.2212
LOG_GDP does not Granger Cause TO		0.45377	0.6354

URB does not Granger Cause LOG_GDP	620	0.83892	0.4327
LOG_GDP does not Granger Cause URB		1.63656	0.1955
FDI does not Granger Cause LOG_GDP	620	0.32604	0.7219
LOG_GDP does not Granger Cause FDI		0.6198	0.5383
REC does not Granger Cause LOG_C02	620	2.63997	0.0722
LOG_C02 does not Granger Cause REC		1.10146	0.3330
TO does not Granger Cause LOG_C02	620	0.57728	0.5617
LOG_C02 does not Granger Cause TO		3.00374	0.0503
URB does not Granger Cause LOG_C02	620	2.77328	0.0632
LOG_C02 does not Granger Cause URB		0.20971	0.8109
FDI does not Granger Cause LOG_C02	620	0.63312	0.5313
LOG_C02 does not Granger Cause FDI		0.03235	0.9682
TO does not Granger Cause REC	620	0.62075	0.5379

REC does not Granger Cause TO		3.79198	0.0231*
URB does not Granger Cause REC	620	0.99724	0.3695
REC does not Granger Cause URB		0.21889	0.8035
FDI does not Granger Cause REC	620	1.07907	0.3406
REC does not Granger Cause FDI		0.25461	0.7752
URB does not Granger Cause TO	620	0.31661	0.7287
TO does not Granger Cause URB		1.10220	0.3328
FDI does not Granger Cause TO	620	1.75535	0.1737
TO does not Granger Cause FDI		0.25780	0.7728
FDI does not Granger Cause URB	620	1.07308	0.3426
URB does not Granger Cause FDI		0.24420	0.7834

Source: *Author's Computation.*

Note: *The asterisk (*) shows that the null hypothesis is rejected.*

Summarises the findings of the Granger causality test, which determines the causal relationship between two variables. The null hypothesis posits no causal relationship between the variables under consideration, as determined by Granger causation. The null hypothesis is used to evaluate the causal relationship between two variables.

Figure 4.8 shows the Granger Causality Test results for all variables such as LogGDP (economic growth), LogC02 (carbon emissions), REC (renewable energy consumption), TO (trade openness), URB (urban population), and FDI (foreign direct investment). The results indicate that LogC02 causes LogGDP, with an F-statistic of 3.01639 and a p-value of 00.0497*. This demonstrates a robust correlation between GDP and C02; conversely, GDP also influences LogC02, with F values of 3.19169 and 0.0418, indicating a strong predictor of GDP and C02 in G20 countries. Therefore, GDP and C02 have a two-way causal relationship that influences each other. Furthermore, renewable energy consumption exhibits a stronger causal relationship with trade openness, as evidenced by the F-statistic result of 3.79198 and the PE value of 0.0231*. This suggests a robust relationship between REC and trade openness, but not vice versa. Therefore, this causal relationship provides new knowledge and insight for policymakers to design a policy that is as effective as possible to achieve sustainable development in G20 countries.

This VAR method enables the unobserved individual heterogeneity associated with panel data and enables all variables in a cross-sectional time series system to influence each other (Zhang et al., 2015). It considers the unique traits of every person or group in the dataset, therefore enabling the unobserved individual heterogeneity linked with panel data. For the benefit of future researchers, the classifications of PVAR models are useful in resolving the matching issue that exists between the process of model setup and the production of data. In a VAR system, all variables are often considered endogenous, with limitations on the indices that may explain the effects of exogenous shocks on the system using theoretical models or statistical data(Abrigo & Love, 2016).

Table 4.9: VAR Estimation Results

	D(LOG_GDP)	D(LOG_C02)	D(REC)	D(TO)	D(URB)	D(FDI)
D(LOG_GDP(-1))	0.137613	0.024907	-0.404293	0.952907	-0.016986	0.253147
	(0.04448)*	(0.02279)*	(0.51948)	(1.70366)	(0.02370)*	(0.55647)
	[3.09389]	[1.09300]	[-0.77827]	[0.55933]	[-0.71671]	[0.45491]
D(LOG_GDP(-2))	-0.12611	-0.016443	0.182251	-3.479575	0.030947	1.471864
	(0.04695)*	(0.02406)*	(0.54837)	(1.79842)	(0.02502)*	(0.58743)
	[-2.68607]	[-0.68356]	[0.33235]	[-1.93479]	[1.23690]	[2.50561]
D(LOG_C02(-1))	0.045390	-0.151286	2.666197	3.176402	0.009406	-1.797331
	(0.12653)	(0.06482)	(1.47775)	(4.84640)	(0.06742)	(1.58300)
	[0.35873]	[-2.33381]	[1.80422]	[0.65541]	[0.13951]	[-1.13540]
D(LOG_C02(-2))	0.174910	-0.017128	2.425883	-11.09351	0.003893	0.023291
	(0.172345)	(0.08830)	(2.01284)	(6.60124)	(0.09184)	(2.15619)
	[1.01489]	[-0.19398]	[1.20521]	[-1.68052]	[0.04239]	[0.01080]
D(REC(-1))	0.006477	-0.005986	0.130604	-0.315191	-0.001630	-0.105230
	(0.00539)*	(0.00276)*	(0.06296)	(0.20649)	(0.00287)*	(0.06745)
	[1.20144]	[-2.16726]	[2.07434]	[-1.52644]	[-0.56746]	[-1.56021]
D(REC(-2))	-0.007718	-0.008019	0.138634	0.218875	-0.001713	0.111351
	(0.00807)	(0.00413)*	(0.09421)	(0.30895)	(0.00430)*	(0.10091)
	[-0.95678]	[-1.94042]	[1.47161]	[0.70844]	[-0.39862]	[1.10342]
D(TO(-1))	-0.000429	-0.000363	0.003902	-0.199177	-0.000239	0.0047239
	(0.00093)*	(0.00048)*	(0.01090)*	(0.03573)	(0.00050)*	(0.01167)
	[-0.45999]	[-0.75870]	[0.35813]	[-5.57381]	[-0.48049]	[0.40469]

D(TO(-2))	-0.000542	-0.00038	0.005301	-0.189360	0.000880	0.007343
	(0.00096)*	(0.00049)*	(0.01121)	(0.03678)*	(0.00051)*	(0.01201)
	[-0.56481]	[-0.78814]	[0.47273]	[-5.14900]	[1.71923]	[0.61129]
D(URB(-1))	0.072136	0.018845	-0.802036	1.328086	1.223634	-0.074142
	(0.072067)	(0.03692)*	(0.84167)	(2.76031)	(0.03840)*	(0.90161)
	[1.00096]	[0.51041]	[-0.95291]	[0.48114]	[31.8645]	[-0.08223]
D(URB(-2))	-0.034977	0.002804	0.292429	-0.616278	-0.265043	0.027139
	(0.07129)	(0.03652)*	(0.83260)	(2.73057)	(0.03799)*	(0.891890)
	[-0.49063]	[0.07677]	[0.35122]	[-0.22570]	[-6.97711]	[0.03043]
D(FDI(-1))	-0.000381	0.001919	-0.031061	0.270113	8.394132	-0.382036
	(0.00329)*	(0.00169)	(0.03845)*	(0.12609	(0.00175)*	(0.04118)*
	[-0.11567]	[1.13784]	[-0.80791]	[2.14228]	[0.04785]	[-9.27625]
D(FDI(-2))	0.001723	0.001169	-0.02345	0.041966	0.000294	-0.192253
	(0.00342)*	(0.00175)*	(0.03990)*	(0.13084)	(0.00182)*	(0.04274)*
	[0.50424]	[0.66795]	[-0.58780]	[0.32073]	[0.16140]	[-4.49837]
C	0.025526	-0.002106	0.104908	0.791950	0.011464	0.004881
	(0.00818)	(0.00419)	(0.09551)	(0.31324)	(0.00436)	(0.10232)
	[3.12121]	[-0.50271]	[1.09835]	[2.52822]	[2.63065]	[0.04771]
R-squared	0.049837	0.041881	0.028837	0.128151	0.954139	0.146719
Adj. R-squared	0.030413	0.022295	0.008983	0.110327	0.953202	0.129275
Sum sq. resids	9.675758	2.539610	1319.788	14195.10	2.747329	1514.474
S.E. equation	0.128388	0.065776	1.499454	4.917566	0.068413	1.606245
F-statistic	2.565739	2.138248	1.452476	7.190115	1017.714	8.411048
Log-likelihood	386.8287	788.1126	-1087.852	-1800.480	764.5270	-1129.131

Akaike AIC	-1.246096	-2.583709	3.669507	6.044933	-2.505090	3.8071048
Schwarz SC	-1.150829	-2.488442	3.764774	6.140200	-2.409823	3.902371
Mean dependent	0.038595	0.004880	-0.059487	0.727395	0.330333	0.031745
S.D. dependent	0.130386	0.066521	1.506234	5.213568	0.316243	1.721359

Source: Author's computation; ***Notes:*** *(*) Significant at 1%; (**) Significant at 5%; (***) Significant at 10% and (no) Not Significant.*
Source: *Author's Computation.*

Table 4.9 shows a strong influence between GDP and itself, with a coefficient value of 0.04448, indicating that the positive effect of past GDP growth on current GDP supports the hypothesis that GDP growth tends to reinforce itself. In addition, the insignificant impact of C02 on GDP illustrates that in this model, environmental factors do not have a strong direct influence on economic growth. On the other hand, renewable energy consumption has a significant relationship, suggesting that REC can influence GDP. Furthermore, the relationship between FDI and GDP has historically been positive and significant, indicating that economic performance can attract foreign investment. Other findings show that CO_2 emissions and trade openness do not have a significant direct effect on GDP.

The results of the VAR estimate for the G20 nations are summarized in Table 4.9. In this estimation, each variable is regressed on its lags up to two lags, as well as lags on other variables. In addition, the results of the VAR will display the coefficients of the lagged variables (logC02), as well as the coefficients of Renewable Energy Consumption, Trade Openness, Urbanization, and Foreign Direct Investment on GDP during the conversion process. The coefficients of the VAR results demonstrate the short-term relationship between variables. Furthermore, if the coefficient demonstrates a positive link, it indicates that there is a positive relationship between the variables, while a negative coefficient indicates that it demonstrates a negative association between the variables. When we look at the table that is located above, we can see that the brackets represent the standard errors, while the square brackets, on the other hand, represent the t statistics. According to the findings of the VAR estimate calculation, we are able to determine that the value of the asterisk signifies significant results in the research. On the other hand, if the VAR estimation results do not have an asterisk, it indicates that the results are not significant.

The Granger Causality test results can be used to verify a causal relationship between C02 and GDP if the VAR estimation results suggest that the main variables are not significant (Kim et al., 2010; Mehrara, 2007; M. Wang, 2018). This will reveal a two-way relationship. With an F-statistic of 3.01639 and a p-value of 00.0497*, Table 4.8 demonstrates that LogC02 induces LogGDP. This suggests a robust correlation between GDP and C02; conversely, GDP also influences LogC02, as evidenced by F-values of 3.19169 and 0.0418, respectively, suggesting a robust predictor of GDP and C02 in G20 countries. Consequently, GDP and CO2 are influenced by one another in a bidirectional manner. On the other hand, this result shows that R2 is low for secondary data because Data collected by the World Bank that is considered secondary depends on the context in which it is used, and particular variables might not be significant in certain situations (Baltagi, 2005). For instance, specific differences between developed and developing countries regarding the factors that drive economic growth may impact how well the model fits the data (Tawiah et al., 2021).

4.1.7 Impulse Response Function (IRF)

Impulse Response Function is a method of describing the variables in the model that are in response to an abrupt or "shock" in the other variables(Lütkepohl, 2005). Furthermore, IRF (Impulse Response Function) is exceedingly advantageous for the examination of VAR (Vector Autoregression) or the dynamics of the correlation between variables in both the short and long term. The IRF (Impulse Response Function) illustrates the magnitude and duration of the effect that a shock to one variable has on other variables.

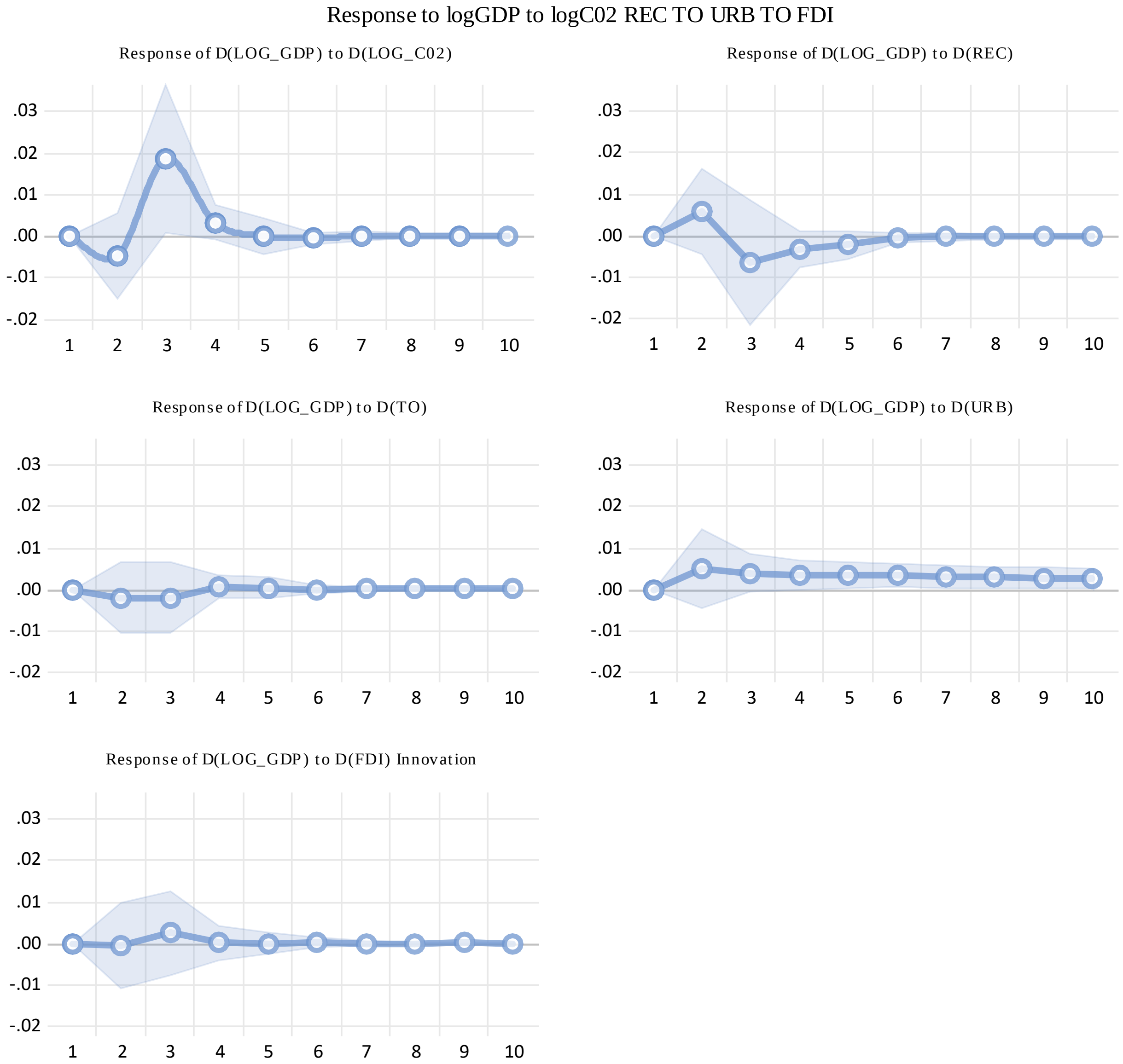


Figure 4.1

Response D(Log_GDP) with some variables (LogC02, REC, TO, URB, FDI)

Figure 4.1 is an impulse response function of the dynamic effects of various shocks on economic growth in G20 countries. At the beginning of the period, CO2 emissions have a negative impact on GDP growth, although the economy should adjust itself and tend to be stable in subsequent periods. However, renewable energy consumption shows that increasing REC positively impacts GDP in both the short and medium term, gradually stabilizing in the long term. Furthermore, trade openness negatively affects the short term but positively contributes to economic growth in G20 countries. Meanwhile, urbanization can significantly increase economic growth in the short term, but its benefits decline and eventually stabilize. Finally, foreign direct investment positively impacts GDP, considerably contributing to medium-term economic growth and fluctuations.

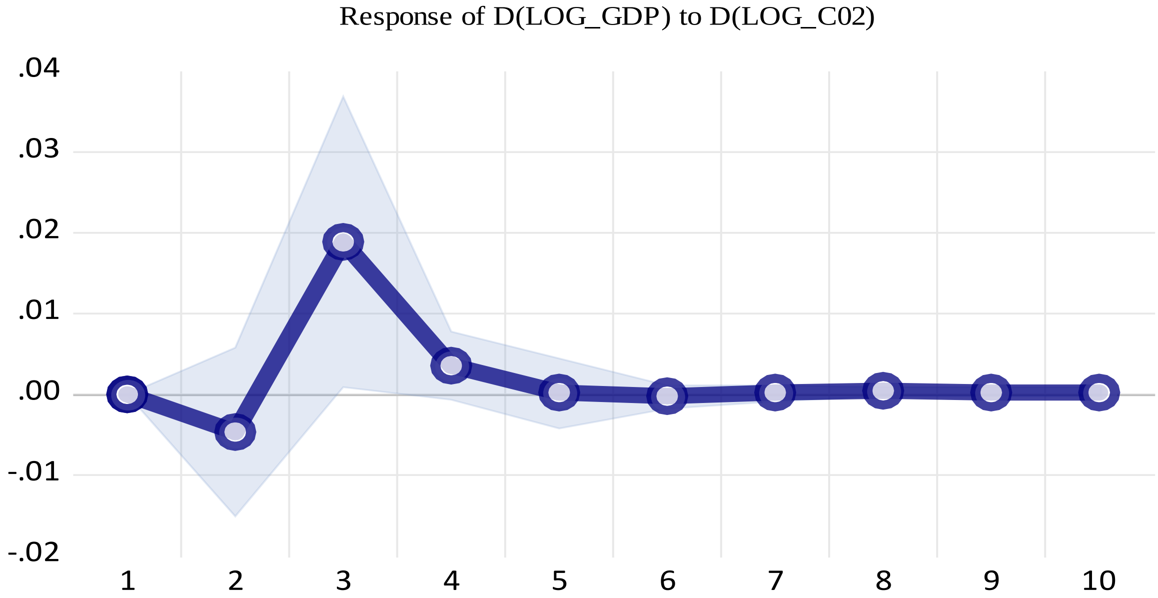


Figure 4. 2 : Response of D(LOG_GDP) to D(LOG_C02)

Figure 4.2 shows the positive and negative impacts on economic growth due to CO2 emissions, with short-term gains followed by long-term declines. Although economic activities that cause emissions can initially increase growth, they are not sustainable and can harm the economy in the long run. Therefore, this analysis emphasizes the importance of sustainable growth practices that balance economic growth with environmental preservation. As shown in Figure 1, GDP has a diverse response to changes in CO2 emissions over time. During the first period, there was no significant response from CO2 emissions to GDP, suggesting that CO2 emissions did not significantly influence short-term economic activity. Furthermore, the second period saw a decreased response, indicating an indirect relationship between CO2 emissions and GDP, potentially influenced by other factors or delayed effects. However, the increase in GDP in the third period experienced a very drastic or significant growth, so the short-term response was positive to the previous changes. Therefore, high CO2 emissions in the early period have the potential to drive economic activity and positively impact GDP.

On the other hand, the impulse response led to a decline in GDP during the fourth period, as the initial positive impact gradually diminished and GDP started to decline, ultimately approaching zero. This indicates a need for a more sustainable positive influence and a gradual decrease over time. In addition, the negative response in the fifth and sixth periods, where the increase in CO2 emissions is expected to be detrimental to GDP, can be seen as having a slight negative impact on GDP. Furthermore, the impulse response in the sixth to tenth period of the GDP response is relatively weak. It is at zero, indicating that the initial shock to GDP fades and, over time, the economic conditions return to stability after previous growth.

Figure 4.2 illustrates a positive response in the short term, where GDP increases with high economic activity. However, over time, the GDP's response to CO2 benefits begins to diminish, and, in the long term, it becomes slightly negative, suggesting that the continuous increase in CO2 emissions could potentially harm economic growth in G20 countries. Therefore, this pattern demonstrates that while the short-term relationship between GDP and CO2 increases GDP, the positive impact is not sustainable and can lead to adverse effects, such as increasing environmental degradation over time, which can negatively impact economic growth. In conclusion, the positive and negative effects of CO2 emissions on economic growth have short-term benefits, but there is a long-term decline. At first, increasing CO2 emissions increases economic growth, but it is not sustainable and can harm long-term economic conditions. Based on this explanation above, C02 emissions are positive in the short term but negative in the long term for GDP in G20 Countries.

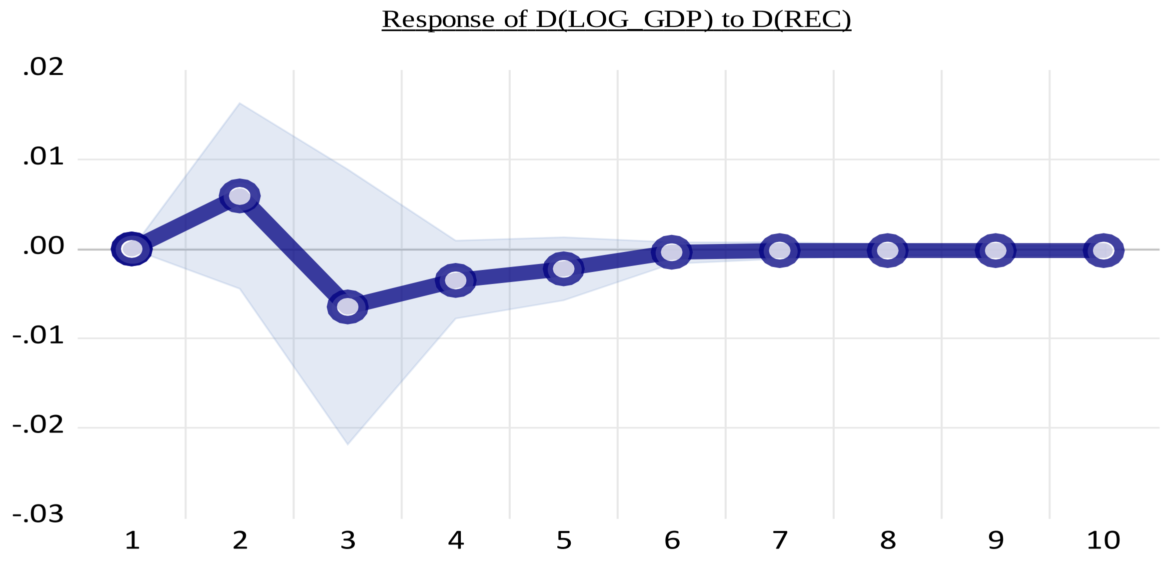


Figure 4.3 : Response of D(LOG_GDP) to D(REC)

Figure 4.3 shows, using the impulse response function, how the use of renewable energy sources (REC) affects GDP in G20 countries. It starts with a first positive GDP reaction to changes in renewable energy consumption, implying that the early investment and economic activity connected with renewable energy projects initially helped strengthen the economy. Moreover, the use of renewable energy rises rather noticeably and is favorable for GDP; this growth indicates that the acceptance of renewable energy has a major impact on economic growth. The economy gains from using renewable energy sources over time, resulting in a positive reaction leading to a declining trend and finally zero in the next period. Transition costs and the disuse of certain fossil fuel infrastructures most certainly led the GDP response to REC emissions to turn negative during the fifth period. Still, the response rises gradually until the seventh through tenth periods.

This suggests that the economy is responding to renewable energy use; REC has little effect on either good or negative economic growth. Moreover, the early GDP reaction to REC emissions indicated a positive one, suggesting that rising renewable energy use will shortly boost economic growth. Conversely, the usage of renewable energy has an appreciable long-term influence on or negative economic growth. This reveals a mixed reaction: The shift challenges economic growth in the G20 countries, even if using renewable energy can yield temporary advantages. Moreover, the economy seems stable again, so the pattern indicates that good and efficient management of renewable energy can maximize the short term and lower the cost of switching to it. Based on the given impulse response function, it can be inferred that REC positively impacts GDP in G20 countries.

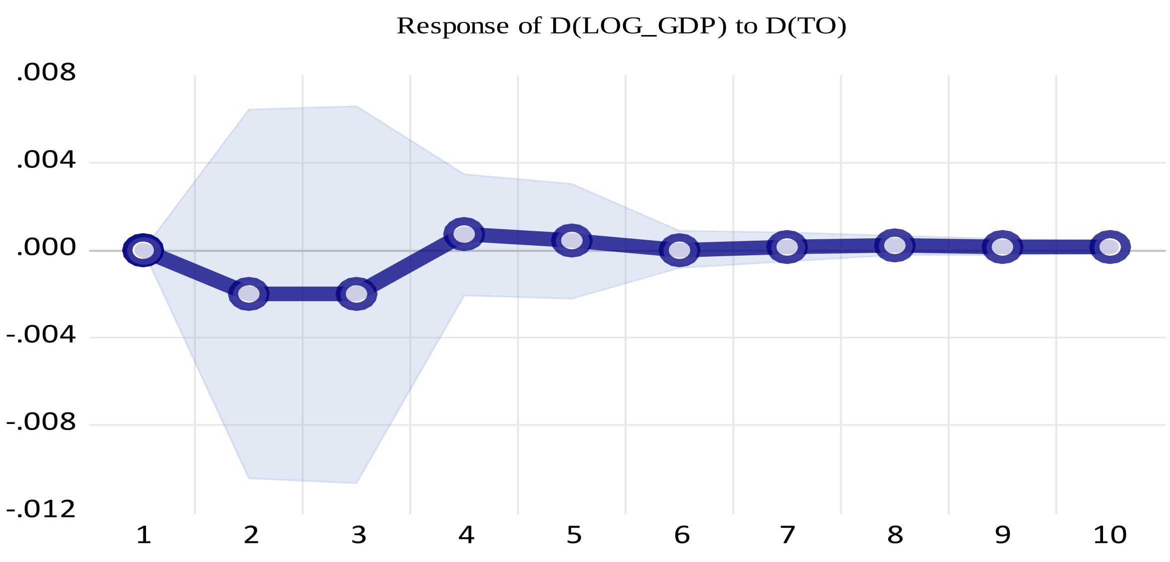


Figure 4.4 : Response of D(LOG_GDP) to D(TO)

Using the impulse response function, Figure 4.4 shows how GDP responds to trade openness (TO) in G20 countries over several periods. Initially, GDP showed something good, although the response to trade openness was still zero. This illustrates that the conditions at the start of the economic period were favorable, but trade openness has yet to have a significant impact. Furthermore, GDP experiences a negative response in the second and third periods, which causes uncertainty and inhibits economic growth. However, in the third to fourth period, trade openness has increased significantly; this indicates that as the adjustment to the economy progresses, it positively impacts economic growth.

Furthermore, the response of GDP to TO is still positive even though GDP is gradually decreasing, and at this time, the economy still benefits from TO. In addition, Trade openness shows stability in the sixth to tenth periods. Therefore, long-term stability demonstrates that economic conditions have been able to adjust to the increase in TO in G20 countries. Thus, examining the response pattern in Figure 4.4 reveals a short-term challenge associated with increased trade openness, while the medium and long-term effects are positive. The initial response is how the economy adjusts to the new trade dynamics. However, if the economy learns to adapt, it will positively affect economic growth. Therefore, drawing from the impulse response function, we conclude that trade openness positively influences economic growth in the G20 countries during the shock period, which typically lasts approximately ten periods.

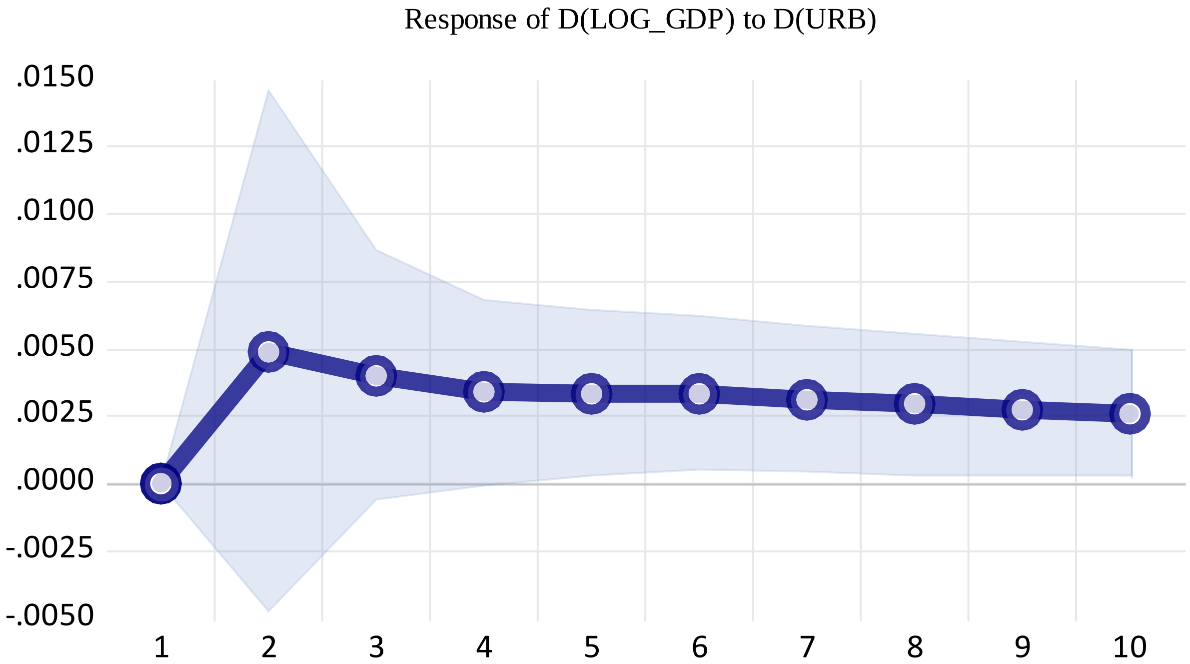


Figure 4.5 : Response of D(LOG_GDP) to D(URB)

Figure 4.5 uses impulse response function analysis to demonstrate how GDP responds to urbanization in G20 countries. Urbanization has a beneficial influence on GDP at the beginning of the era, but it peaks in the second. This is related to the continuing urbanization, which enhances economic growth in the near term in the G20 countries. Furthermore, in the third period, the GDP response to urbanization decreased, showing a progressive reduction in the initial economic boom associated with urbanization. However, a further reduction happened in the fourth session, when the reaction remained positive but fell rather than zero. This demonstrates that urbanization can contribute to economic growth, but its influence diminishes with time in G20 countries.

After the fourth period, the positive response remained above zero, even though it continued to fall, showing that urbanization's beneficial influence on GDP will persist in the long run. Besides, urbanization has various effects, and it typically promotes economic growth. Besides, the short-term advantages demonstrate that urbanization leads to higher economic productivity and better infrastructure use, which boosts economic activity in G20 countries. However, urbanization's benefits diminish with time due to rising living expenses and greater traffic congestion. In conclusion, urbanization has a beneficial influence on economic growth in G20 countries, while the initial boost fades with time. Based on the impulse response function presented above, we may deduce that urbanization positively impacts GDP in G20 countries.

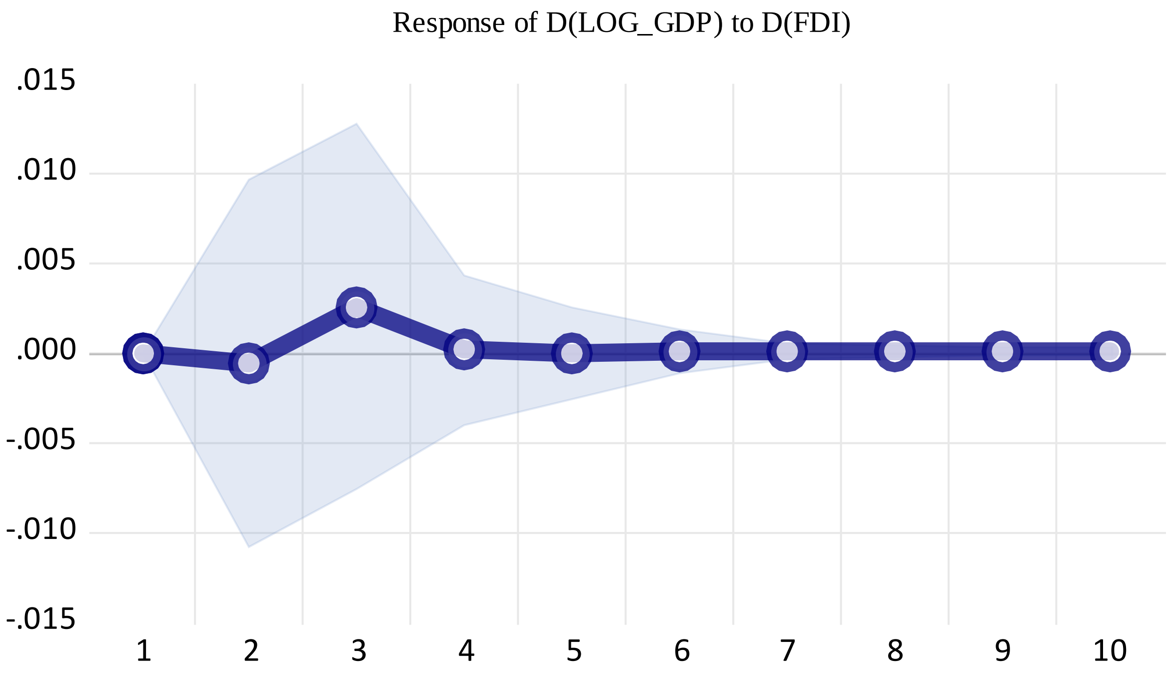


Figure 4.6 : Response of D(LOG_GDP) to D(FDI)

Figure 4.6 shows the impulse response function of how GDP responds to the shock or innovation of foreign direct investment over time. In the first period, GDP did not change, which shows that there was no direct impact of the FDI shock and that the short-term effects of FDI on economic growth were neutral. In the second period, the influx of foreign capital and competition with local businesses led to a negative GDP response to FDI. Then, after responding negatively, there was a significant positive increase in the third period, indicating that after the initial adjustment is complete, FDI can benefit economic growth. However, GDP decreases in the fourth period due to foreign direct investment, indicating that the initial FDI impulse has little sustainable impact and is likely to fluctuate. Furthermore, the transition period between the fourth and fifth periods undergoes a slight decline before stabilizing in the fifth period, and this cycle continues until the tenth period. Based on the explanation above, foreign direct investment positively affects G20 countries.

4.1.8 Forecast Error Variance Decomposition (FEVD)

One of the methods in VAR analysis is variance decomposition; variance decomposition is one of the techniques to determine the proportion of variation in the prediction error of a particular variable attributed to the unexpected changes in other variables in the VAR analysis(Gujarati & Porter, 2009; Wooldridge, 2016). In addition, it illustrates the need for a more comprehensive understanding of the extent to which external forces can influence the internal variables in the model.

Table 4.10: Variance Decomposition *Estimation Result*

Variance Decomposition of D(LOG_GDP)							
Period	**S.E.**	**D(LOG_GDP)**	**D(LOG_C02)**	**D(REC)**	**D(TO)**	**D(URB)**	**D(FDI)**
1	0.128388	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.129907	99.49395	0.133420	0.203147	0.023723	0.143596	0.002165
3	0.131807	97.08552	2.150216	0.445161	0.047664	0.232585	0.038854
4	0.131966	96.88720	2.210343	0.515562	0.050178	0.297885	0.038833
5	0.132037	96.79424	2.207981	0.545380	0.050970	0.362636	0.038797
6	0.132081	96.72982	2.207518	0.546358	0.050935	0.426546	0.038823
7	0.132119	96.67469	2.206307	0.546544	0.050981	0.482676	0.038803
8	0.132152	96.62606	2.205489	0.5466267	0.051140	0.531902	0.038785
9	0.132182	96.58276	2.204657	0.546809	0.051206	0.575791	0.038779
10	0.132208	96.54395	2.203936	0.547012	0.051250	0.615084	0.038769
Variance Decomposition of D(LOG_C02)							
Period	**S.E.**	**D(LOG_GDP)**	**D(LOG_C02)**	**D(REC)**	**D(TO)**	**D(URB)**	**D(FDI)**
1	0.065776	6.869681	93.13032	0.000000	0.000000	0.000000	0.000000
2	0.066273	6.909931	91.94984	0.851482	0.037225	0.040228	0.21129394
3	0.067231	6.714477	90.63106	2.248015	0.071928	0.126365	0.208156
4	0.067279	6.705105	90.51195	2.255900	0.080611	0.233200	0.213238

5	0.067321	6.698114	90.39911	2.274819	0.081076	0.330913	0.215968
6	0.067351	6.692199	90.31874	2.273437	0.081009	0.418830	0.215783
7	0.067377	6.687039	90.24904	2.272200	0.081185	0.494894	0.215645
8	0.067400	6.682530	90.18709	2.271099	0.081359	0.562391	0.215533
9	0.067421	6.678471	90.13176	2.270302	0.081402	0.622651	0.215413
10	0.067440	6.674834	90.08226	2.269628	0.081453	0.676528	0.215298
Variance Decomposition of D(REC)							
Period	**S.E.**	**D(LOG_GDP)**	**D(LOG_C02)**	**D(REC)**	**D(TO)**	**D(URB)**	**D(FDI)**
1	1.499454	2.190091	54.65051	43.15940	0.000000	0.000000	0.000000
2	1.507905	2.242082	54.06615	43.44383	0.005592	0.135412	0.106934
3	1.515944	2.242914	53.49429	43.87478	0.0186222	0.253930	0.115461
4	1.516891	2.241285	53.429367	43.82091	0.024728	0.357120	0.126593
5	1.517602	2.239917	53.38625	43.77989	0.026263	0.440257	0.127418
6	1.518146	2.238322	53.34809	43.74885	0.026258	0.511052	0.127429
7	1.518614	2.236940	53.31519	43.72198	0.026380	0.572093	0.127421
8	1.519036	2.235810	53.28592	43.69812	0.026565	0.626212	0.127374
9	1.519414	2.234754	53.25967	43.67690	0.026629	0.674718	0.127328
10	1.519752	2.233797	53.23616	43.65794	0.026690	0.718139	0.127274
Variance Decomposition of D(TO)							
Period	**S.E.**	**D(LOG_GDP)**	**D(LOG_C02)**	**D(REC)**	**D(TO)**	**D(URB)**	**D(FDI)**
1	4.917566	7.031235	2.931294	2.251369	87.78610	0.000000	0.000000
2	5.076101	7.662753	3.416851	2.888873	85.28172	0.036189	0.713616
3	5.295938	7.956782	8.391436	2.673721	80.18121	0.052482	0.744369
4	5.313902	7.919803	8.526194	2.690025	80.01396	0.052481	0.797536
5	5.318330	7.975723	8.518408	2.719822	79.91930	0.053680	0.813063
6	5.319507	7.972459	8.522179	2.722555	79.91345	0.055585	0.813770

7	5.319677	7.974842	8.521669	2.722387	79.90836	0.056803	0.815936
8	5.319775	7.974847	8.522018	2.722334	79.90702	0.057812	0.815967
9	5.319811	7.974830	8.521905	2.722370	79.90597	0.058870	0.816053
10	5.319839	7.974761	8.521824	2.722369	79.90516	0.059823	0.816060
Variance Decomposition of D(URB)							
Period	**S.E.**	**D(LOG_GDP)**	**D(LOG_C02)**	**D(REC)**	**D(TO)**	**D(URB)**	**D(FDI)**
1	0.068413	0.003027	0.006834	0.146751	0.010918	99.83247	0.000000
2	0.108199	0.028909	0.022485	0.270903	0.004739	99.67281	0.000152
3	0.137429	0.021808	0.138050	0.405877	0.082255	99.35004	0.001971
4	0.160015	0.047851	0.228986	0.523882	0.126237	99.06779	0.005253
5	0.178060	0.059913	0.266263	0.617440	0.134202	98.91476	0.007421
6	0.192867	0.064231	0.293621	0.682805	0.140794	98.81023	0.008321
7	0.205253	0.067981	0.313748	0.727330	0.147451	98.73446	0.009026
8	0.215756	0.070982	0.327171	0.760056	0.151663	98.68051	0.009622
9	0.224756	0.073039	0.336836	0.784573	0.154585	98.64095	0.010022
10	0.232528	0.074613	0.344400	0.803319	0.156985	98.61036	0.010323
Variance Decomposition of D(FDI)							
Period	**S.E.**	**D(LOG_GDP)**	**D(LOG_C02)**	**D(REC)**	**D(TO)**	**D(URB)**	**D(FDI)**
1	1.606245	0.159030	0.531375	0.101068	1.509590	0.0177633	97.68117
2	1.722403	0.139413	0.511192	0.569156	1.409991	0.021363	97.34888
3	1.741075	0.897387	0.976628	1.276711	1.385454	0.021008	95.44281
4	1.747740	0.940689	1.013840	1.274515	1.376263	0.021149	95.37354
5	1.748802	0.968432	1.042094	1.280551	1.375350	0.021326	95.31225
6	1.748978	0.976744	1.047229	1.281746	1.376233	0.021419	95.29663
7	1.749023	0.976846	1.047185	1.281818	1.376217	0.021421	95.29651
8	1.749030	0.977255	1.047213	1.281831	1.376270	0.021432	95.295600

9	1.749031	0.977265	1.047219	1.281844	1.376289	0.021448	95.29593
10	1.749032	0.977270	1.047218	1.281844	1.376288	0.021459	95.29592

Note: *Cholesky Ordering: DLOGGDP DLOGC02 REC TO URB FDI*
Source: *Author's Computation*

The result of the variance decomposition analysis in table 4.10 explains three main variables and three control variables: d (Log_GDP), d (Log_C02), renewable energy consumption, trade openness, urbanization, and foreign direct investment. In addition, the results of the variance decomposition analysis can be used to measure the contribution of each variable to the prediction error in the variance of the dependent variable in the Panel VAR for ten periods.

The first result shows that the variance of the forecast error d (log) explains the relationship between GDP and GDP by 100.000%. The results of the variance composition analysis in d (log_C02), renewable energy consumption, trade openness, urbanization, and foreign direct investment are also 100.000% in the initial period. In addition, the forecast error of the relationship between GDP and GPD itself decreased to 99.49395%; in addition, the forecast error on other variables increased, including d(log_C02) by 0.030712%, Renewable Energy Consumption by 0.2023147%, Trade openness by 0.23723%, urbanization by 0.143596%, and foreign direct investment by 0.002165% in the second period. Finally, from the third to the tenth period, C02's contribution to the GDP forecast error increased to 0.0541157%. In conclusion, the variance of the forecast error D (LOG_GDP) initially thoroughly explains itself, indicating that internal factors of GDP itself influence it in the short term. Over time, other contributions to the error variance, such as C02 emissions, REC, trade openness, and foreign direct investment, increased. Besides, this contribution is still relatively small compared to GDP itself. This explains why, in the long term, internal factors still heavily influence GDP despite the influence of external variables.

The second table in Figure 4.10 shows the variance decomposition results for the variable D (LOG_CO2), which is the change in CO2 emissions. In the early period, the variance of the C02 forecast error is almost entirely explained by itself, which is 93.13032%. This indicates that internal factors within the C02 variable primarily influence C02 emissions in the short term. On the other hand, GDP accounts for 6.869681% of the variance of the CO2 emission forecast error. Then, the contribution of D (LOG_CO2) to the forecast error variance decreases to 91.94984% in the second period, where internal factors are still dominant. However, there is a slight increase in other variables. In this case, the contribution of GDP can be seen, even though it is still relatively small. Furthermore, in the period up to the tenth, there was a decrease of 0.5488% from 90.63106% to 90.082226%; this shows that over time, the influence of other variables on emission forecasting errors has increased slightly but is still relatively small and insignificant.

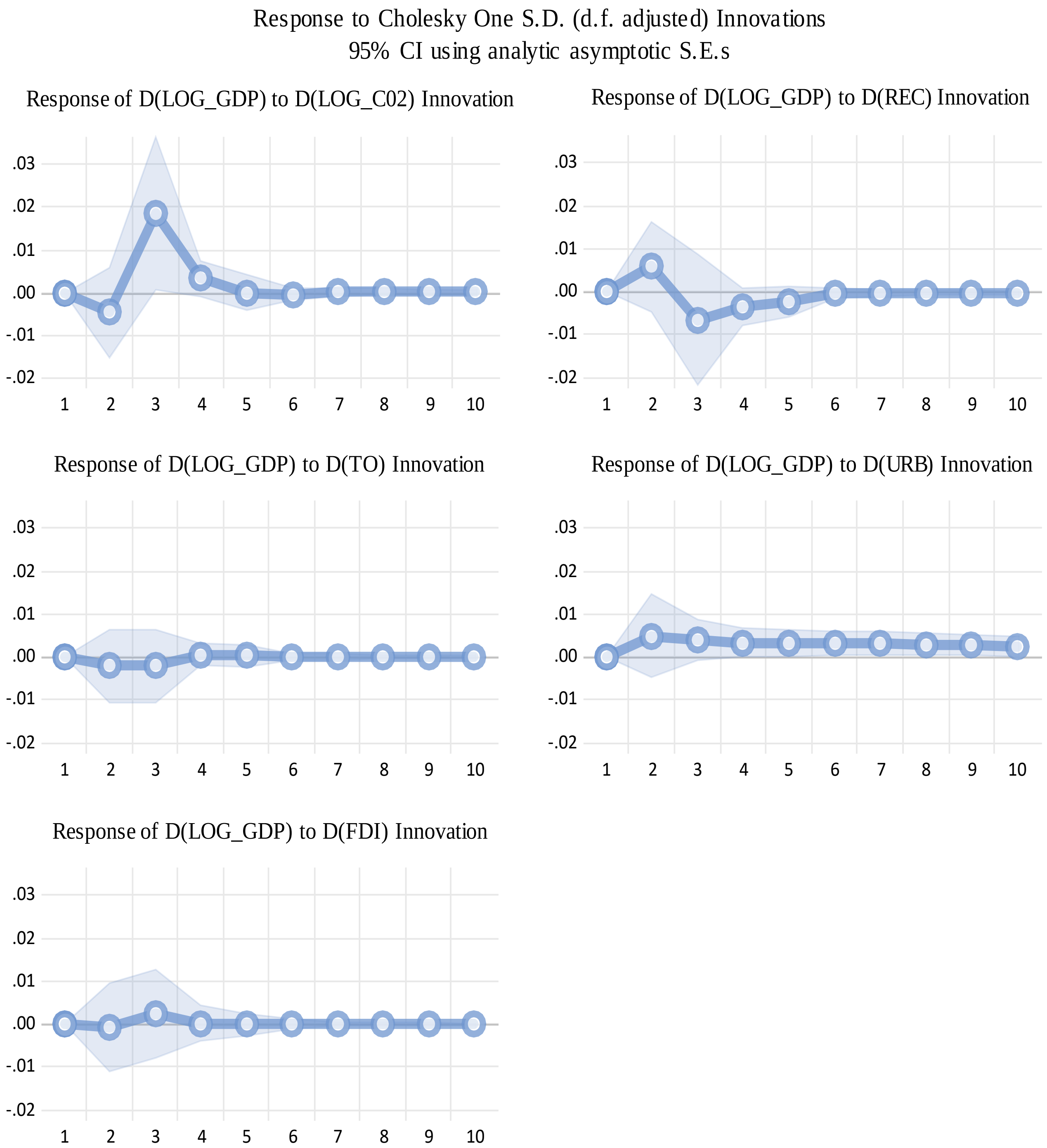
The third table in Figure 4.10 displays the variance decomposition findings for Variable D (REC), representing the change in renewable energy consumption. In the first period, the variation of the CO2 projection error is nearly fully explained by the variable itself, accounting for 43.15940%. This suggests that exogenous influences in the REC variable mostly influence REC emissions in the near run. On the other hand, C02 is responsible for 54.65051% of the variation in REC prediction error, which is rather substantial. Then, GDP contributes 2.190091% of the prediction error variation in REC. Furthermore, between the second and tenth periods, the percentages declined by 0.21411, from 43.44383% to 43.65794%. The variance decomposition analysis of D(REC) provides light on the dynamic links that exist between the use of renewable energy and a number of economic and environmental factors so that these relationships may be better understood. Both the variable levels of carbon dioxide consumption and the historical values of renewable energy sources significantly influence the use of renewable energy in the short term. Even though the effect of previous values gradually declines over time, carbon dioxide continues to be a strong predictor, and other factors begin to contribute more substantially to the variation in the amount of renewable energy used.

Table figure 4.10 shows that in the initial period, the forecast of the relationship between urbanization and itself was 99.83247%. Furthermore, the decline in the estimates between URB and itself decreased in the second period by 99.67281%, as did the forecast error on other variables such as DLOGGDP by 0.028909, LOGC02 by 0.22485%, DREC by 0.270903, DT0 by 0.004739, and DFDI by 0.000152%. However, in the third to tenth periods, the DURB mispricing fluctuates, with the most drastic decrease being 98.61036% in period ten, and other mispricings are obtained in other variables. Furthermore, figure 4.10 shows that there is a relationship between FDI and FDI itself by 97.68117% in the initial period, which is explained by other variables such as DLOGGDP by 0.159030%, DLOGC02 by 0.53137, DTO by 1.509590, and DURB by 0.01776633%. However, in the second to tenth period, DFDI experienced a decline until it reached 95.29592%.

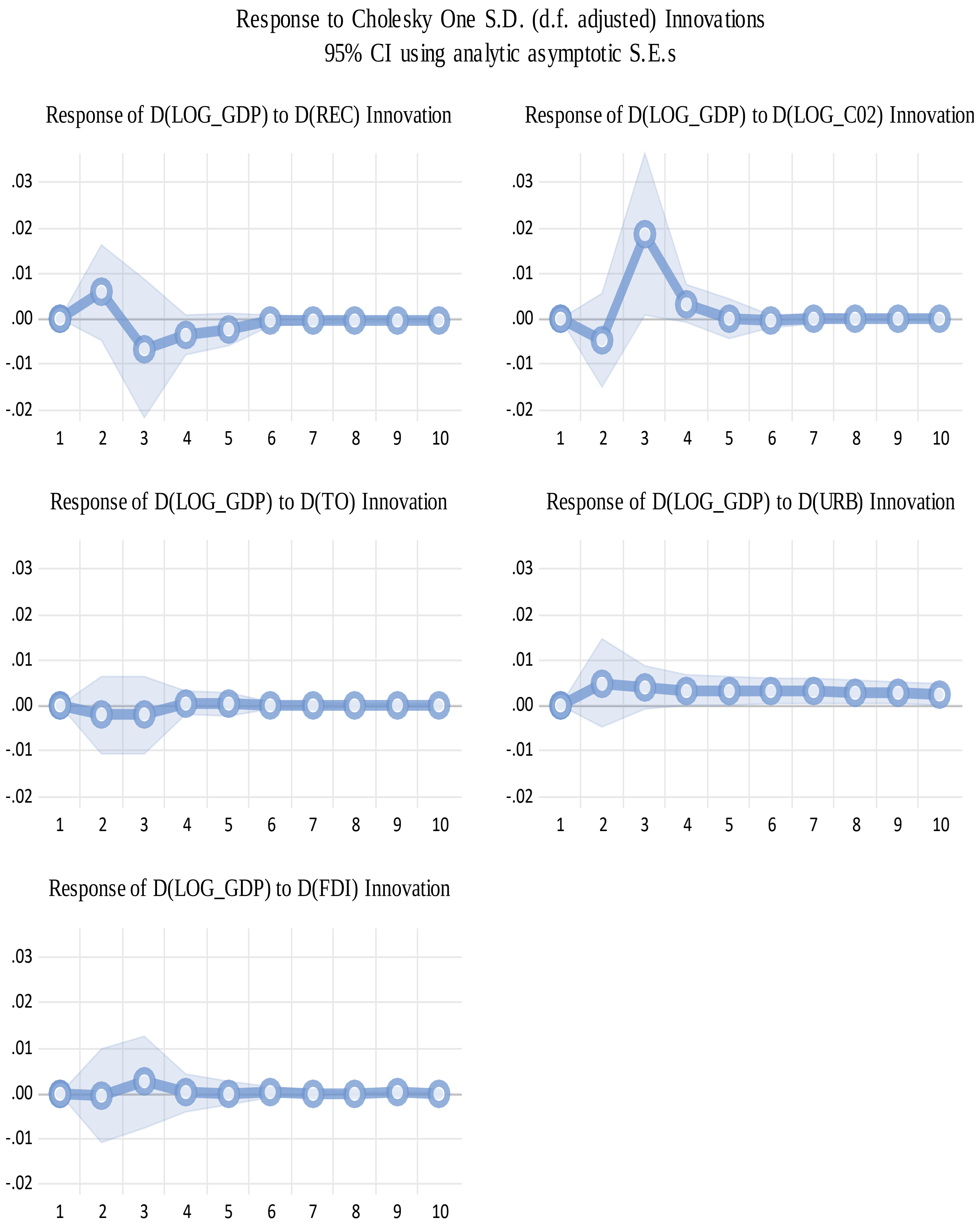
4.1.9 Robustness

In testing the robustness of the impulse response fuctions in the model, we conducted a sensitivity analysis of the model by changing the order of the variables to the dependent variable in order to see the robustness of the model changes (Grossmann et al., 2014), among others:

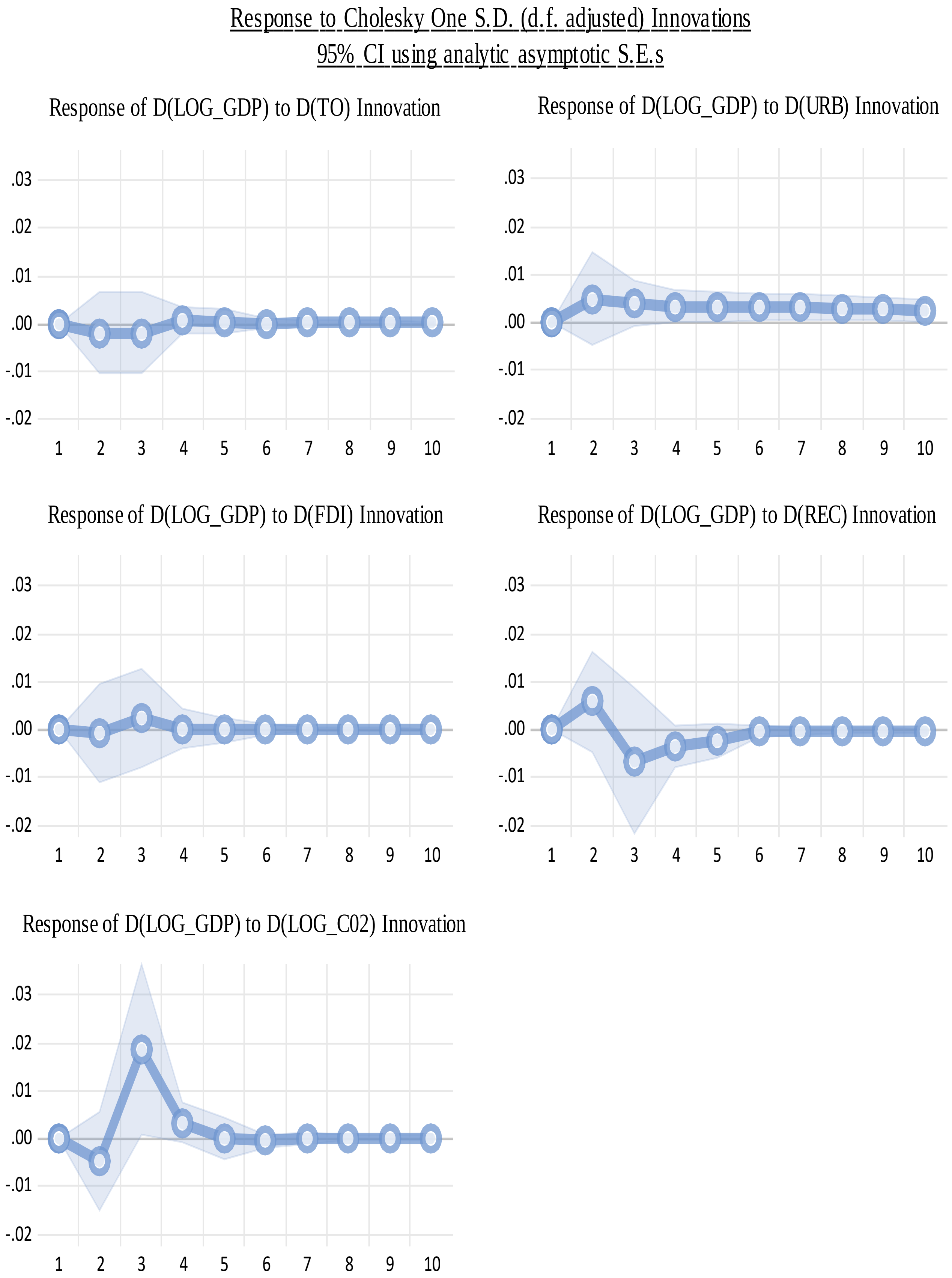
1) GDP → C02 → REC → TO → URB → FDI



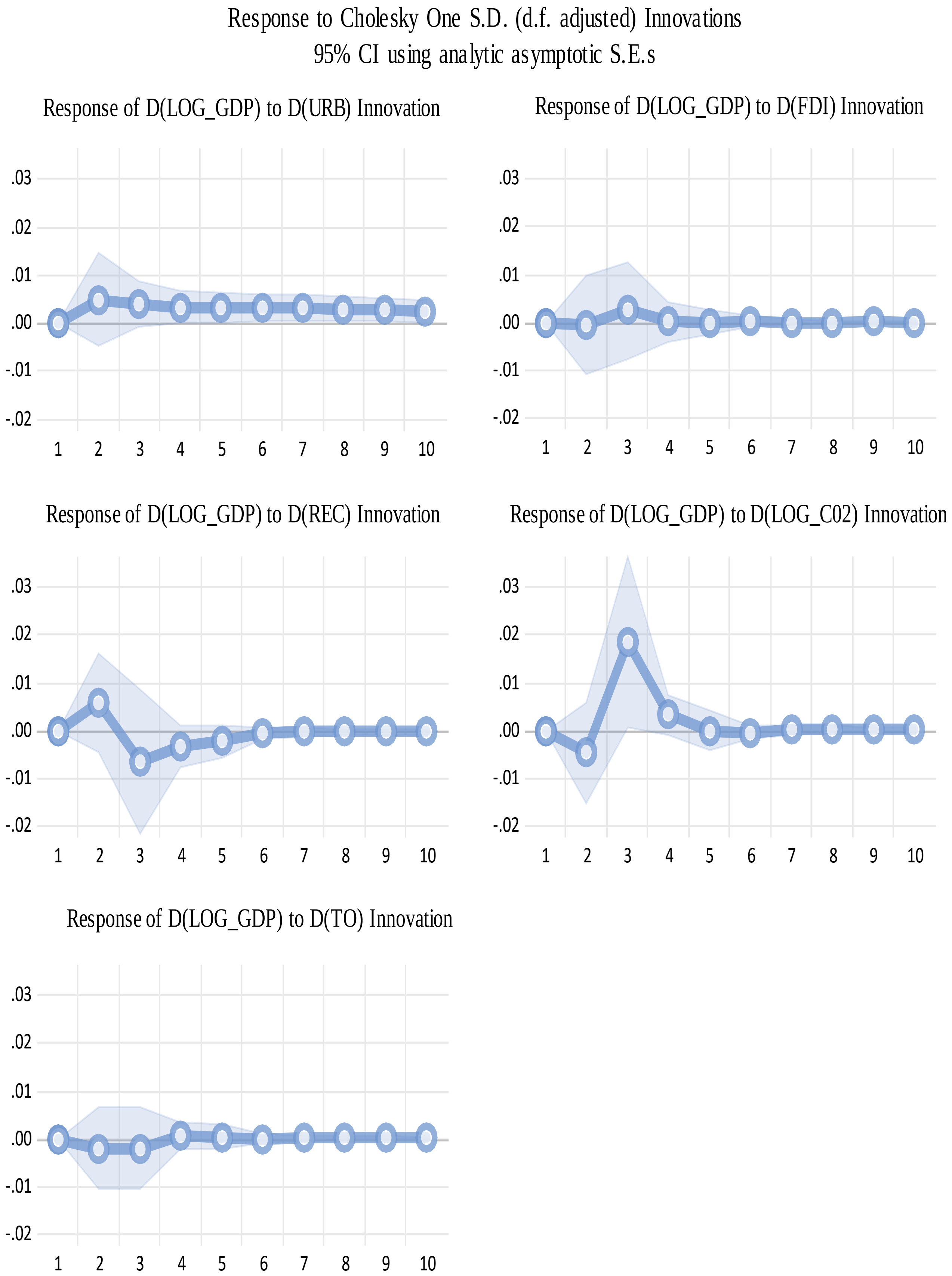
2) GDP → REC → C02 → TO → URB → FDI



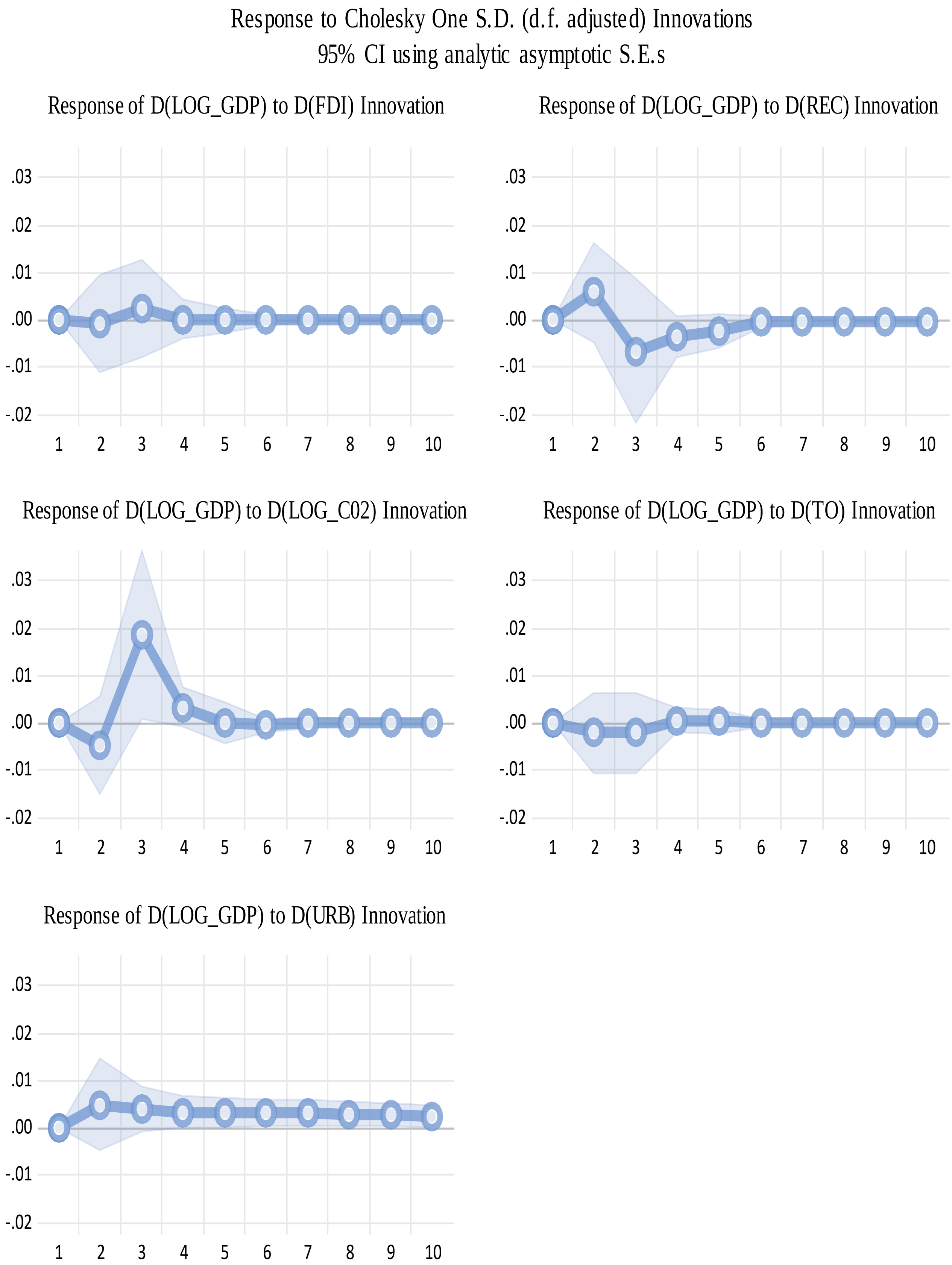
3) GDP → TO → URB → FDI → REC → C02



4) GDP → URB → FDI → REC → CO2 → TO



5) GDP → FDI → REC → C02 → TO → URB



In the findings of the impulse response function, we find that the GDP response to all independent factors is unaffected by changes in the order of the variables. Consequently, the impulse response function results have shown resilience in the variance decomposition results. The impulse response function analysis results show that the response of GDP to the independent factor has no effect on the change in the order of the variables, indicating the robustness of the results. In addition, this robustness identifies that the impulse response function (IRF) results are consistent and reliable and is further supported by the variance decomposition results in table 4.8. This shows that even if the order of the variables is changed, the main relationships and the overall dynamics obtained by the IRF results remain unchanged.

4.2 Discussion and Findings

4.2.1 The dynamic interrelationships of the shocks of C02 emissions on short- and long-term economic growth in G20 countries.

The dynamic interrelationship of short- and long-term C02 emission shocks to GDP in G20 countries is a comprehensive problem. In addition, the short-term impact of these shocks can create indirect economic fluctuations. In contrast, in the long term, these shocks contribute to climate change and the costs of transitioning from non-renewable to renewable energy consumption. In addition, the ability of G20 countries to overcome these problems and challenges leads to low-carbon goals. For instance, the G20 countries represent over eighty percent of the global GDP and have contributed to almost eighty percent of carbon emissions in the global energy industry (Sucahyo & Arsala Rahmani, 2023).

These impulse response function results demonstrate the importance of understanding GDP and its influencing factors. In addition, the results show that CO_2 emissions, renewable energy consumption, trade openness, urbanization, and foreign direct investment can affect GDP in G20 countries. However, the GDP's impulse response function to CO_2 is positive, indicating that CO_2 has a short-term positive impact on GDP and economic growth in G20 countries. However, over time, the GDP's response to CO_2 shows a negative effect. Besides, increasing CO_2 emissions can lead to an increase in CO_2 emissions in G20 countries, which, if not addressed, could negatively impact economic growth in these countries. In addition, research by Mardani et al., (2018) indicates a positive correlation between economic growth and CO_2 emissions in G20 countries. This indicates that there is a positive association between

GDP and CO_2 in the nations that make up the G20, even though some of the G20 members have adopted renewable energy, which, in addition to contributing to economic development, also indirectly contributes to an increase in CO_2 emissions in the G20 countries. In contrast to Niyonzima et al. (2022), the ECM analysis reveals that the long-term correlation between GDP and C02 emissions is positive due to the slow pace of low-carbon policies, but the short-term relationship is negative.

The rise in GDP during the third period was abrupt or considerable, indicating that the short-term reaction to the changes experienced in the previous periods was favorable. Consequently, significant levels of carbon dioxide emissions during the first phase have the potential to stimulate economic activity and have a beneficial influence on GDP. Moreover, there is a favorable immediate reaction, whereby the Gross Domestic Product (GDP) rises in correlation with heightened economic activity. Nevertheless, as time passes, the positive impact of CO_2 benefits on GDP gradually decreases and eventually becomes somewhat negative in the long run. This implies that the ongoing rise in CO_2 emissions has the potential to affect economic growth in G20 countries adversely. This is a result supposed by Alyasari & Alzawbaee (2020) that economic growth harms C02 emissions. In addition, this is in line with EKC; it has been shown that an increase in economic and industrial growth alone is not enough to reduce greenhouse gas emissions globally(Alakbarov et al., 2024).

On the other hand, at low levels of development, economic growth is closely related to environmental degradation. However, when income reaches a certain point, it will impact growth and can improve environmental quality(Alakbarov et al., 2024). Previous research by Alyasari & Alzawbaee (2020) shows that increased carbon dioxide emissions will negatively impact economic growth. This is supposed by Aye & Edoja, (2017) that economic growth is positively correlated with CO_2 emissions, and this correlation grows stronger as economic growth rises. In addition, the correlation between economic development, rising CO_2 emissions, and energy consumption is well-established. A rise in CO_2 levels is known to have detrimental environmental effects. The similar findings by Osobajo et al., (2020) economic growth can cause environmental degradation due to the effects of development and industrialization in developing and developed countries.

The relationship between income and carbon emissions is relevant to the EKC hypothesis, which states that as a country's income increases, it can gradually reduce the increase in C02 emissions in a country(Gillani & Sultana, 2020). Using the Granger causality test, the study found a causal relationship between economic growth, urbanization, and CO2 emissions(Khoshnevis et al., 2019). This shows a significant relationship between income and carbon emissions, which is relevant to the Environmental Kuznets Curve (EKC) hypothesis. The theory states that when a country's income rises, it can gradually reduce the increase in CO2 emissions(G. M. Grossman & Krueger, 1995; Mendoza et al., 2021). In addition, countries that are still experiencing the transition from non-renewable energy to renewable energy must have concrete and targeted policy actions so that the implementation of C02 emission reductions can be carried out while increasing economic growth in G20 countries effectively and efficiently.

4.2.2 The dynamic interrelationships of the shocks of Renewable Energy Consumption on short- and long-term economic growth in G20 countries.

The dynamic interrelationship of renewable energy consumption shocks on short-term and long-term economic growth in G20 countries is a comprehensive problem. In addition, in the short run, the response of GDP to C02 causes economic adjustment due to direct economic adjustment, while in the long run, the shock has a positive impact on sustainable development. Therefore, the ability of G20 countries to transition to renewable energy is essential to the world economy because the G20 has the largest income in the world and has made a significant contribution to the increase in C02 emissions.

Renewable energy can help boost economic growth in the long run. However, the initial transition harms GDP due to the costs involved in switching from non-renewable to renewable energy. This is supposed study by Shahbaz et al.,(2020) examined renewable energy's significant and positive impact on economic growth. Furthermore, the GDP's first response to REC emissions was positive, suggesting that the increasing use of renewable energy sources would likely increase economic development shortly. Conversely, using renewable energy sources does not significantly impact the economy's expansion over the long term, either positively or negatively. In addition, the economy is returning to its previous state of stability, which suggests that effective management of renewable energy sources may optimize the short-term benefits. However, it will decrease GDP for long-term conditions.

The GDP impulse response function to C02 shows positive results, which indicate that an increase in renewable energy sources can increase economic growth in a country. Therefore, the results of the impulse response function of GDP to C02 identify that an increase in renewable energy sources usually also refers to a much lower reduction in C02 emissions, which is associated with economic growth. In addition, the renewable energy transition can have a positive impact on a country's economy, which can be one of the ways to increase economic growth. This finding can be immediately formulated as a policy that suits the needs of G20 members. Furthermore, employing sustainable technology is a viable approach to sustain economic expansion while mitigating the rise in CO2 emissions (González-Álvarez & Montañés, 2023). The results conducted by Gillani & Sultana, (2020) indicate that policymakers in the ASEAN region promptly develop or promote economic policies that promote the adoption of renewable energy by providing fiscal and regulatory policy incentives tailored to the country's specific conditions.

The impulse response function from GDP to REC results shows that G20 countries must begin to transition to renewable energy to not depend on fossil fuels, which can increase C02 emissions in G20 countries both in the short and long term. One way to overcome high-emission economic activity is to implement a policy regarding green economic growth (Feriansyah et al., 2022a). Therefore, concrete steps need to be taken to reduce the negative impact on economic activity, hence the need to adopt sustainable and environmentally friendly policies with green growth, which can reduce emissions and encourage environmentally friendly industrial activities while maintaining economic growth. Another result research by

On the other hand, while reduced energy use causes a short-term decline in economic growth, stakeholders and policymakers still need to fully understand the long-term impacts on energy consumption and CO2 emissions (Mitić et al., 2022). The statement follows the impulse response function of GDP to REC. Although energy consumption can cause a short-term economic decline, it is necessary to consider the long-term effects of energy consumption and CO2 emissions. Therefore, policymakers and relevant stakeholders can properly consider the potential benefits of reducing renewable energy consumption on economic growth. In conclusion, the energy transition negatively impacts the short term and can result in losses. However, it will have a positive impact on the long-term GDP by proportionally prioritizing the sustainability of economic growth.

In addition, one factor preventing the application of renewable energy sources is the lack of financial resources in EU countries, whose primary income still relies on non-renewable energy sources (Ntanos et al., 2018). This is supposed by (Bhuiyan et al., 2022) that using renewable energy technology requires money, and it is necessary to design an effective and efficient policy. As a result, one way to overcome the limited budget is to design policies that are proportional to the country's needs and support renewable energy development. To encourage renewable energy projects, we can provide subsidies and financial incentives. In addition, renewable energy sources are the primary source of income for the European Union. In fact, renewable energy has a positive impact on economic growth of 58% in Australia, Canada, Japan, Germany, United Kingdom, United States, Sweden, Netherlands, Ireland, India, South Africa, Spain etc (Shahbaz et al., 2020) Stated another, a nation switching to renewable energy is probably going to see significant economic development. Furthermore, the shift to renewable energy may have a major and favorable influence on economic development, therefore helping the government and other interested parties. Furthermore, the findings highlight the need to examine the dynamic relationship between GDP and other factors and use this knowledge to develop policies that align with the specific circumstances of the G20 nations.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In this last chapter, we present conclusions, policy suggestions, and future research to provide insight into the general observations and discoveries based on the study results. Furthermore, we also provide the study's limits to facilitate the conduct of more complete future research.

5.1 Conclusion

This research contributes significantly to several parties, both academics and non-academics, on how the dynamic interrelationship between CO2 emissions and renewable energy consumption affects economic growth in G20 countries in the short and long term. Therefore, we will provide conclusions from the findings that have been obtained, among others:

a) The results found that the short-term impact of CO2 positive impacts GDP in economic growth in the G20 countries. This shows that many G20 countries' sectors still depend on fossil fuels, which increase C02 emissions. In addition, when industries start to develop with more energy consumption, it will directly impact higher GDP growth and economic activity. This short-term economic growth activity is significant for G20 countries because it can increase income, employment, and economic stability at that time. However, the relationship between C02 emissions and GDP cannot be sustained for long due to the effects of increasing C02 emissions in G20 countries: Environmental degradation, Health Impacts, and shifting to a more sustainable direction.

b) The results of research findings in the long-term relationship between C02 emissions and GDP have a negative impact, so there is a need for a transition from non-renewable energy to renewable energy, especially for G20 members who still make fossil fuels a source of state income. Furthermore, although there are economic benefits in the short term from C02 emissions to economic growth, it is different when viewed in the long term, namely negative impacts such as environmental damage and some health problems that can be one of the factors reducing income growth in G20 countries.

c) The short-term findings of the relationship between Renewable Energy Consumption and GDP are positive due to the increase in renewable energy consumption associated with an increase in GDP. Furthermore, investment in renewable energy infrastructure such as wind, solar, solar, and hydropower can encourage economic activity, create jobs, and increase economic growth.

d) The long-run results show that Renewable Energy Consumption harms economic growth. This identifies that although renewable energy can boost the economy in the short term, factors and policies are among the most essential factors in determining economic growth in the long term in G20 countries. In addition, there are some long-term benefits that governments will find it easier to reduce CO2 emissions while significantly increasing economic growth in the G20 countries.

5.2 Policy Recommendations

Based on the findings of the study on the dynamic interrelationships of C02 emissions and renewable energy consumption on economic growth in G20 countries using the Panel VAR approach, several policy recommendations can be made by the G20 countries, including:

Firstly, the G20 countries can encourage renewable energy consumption because it positively impacts GDP, which shows the need for renewable energy infrastructure to encourage sustainable economic growth. In addition, the G20 countries must be able to prioritize funding for renewable energy programs, such as hydropower, solar power, sun and wind, etc. Where this can be obtained through several sources, including grant subsidies. Furthermore, there is a need to accelerate the use of renewable energy to reduce dependence on fossil fuels and reduce C02 emissions over time in the G20 countries.

Secondly, the G20 can increase energy efficiency standards to reduce CO2 emissions without reducing economic growth. In addition, the G20 countries should set more comprehensive energy efficiency standards for the building industry and transportation sector. In addition, the G20 can take real action in promoting environmentally friendly and energy-efficient technologies, where G20 countries can reduce energy consumption and emissions to improve the sustainability of economic activities in G20 countries. In conclusion, G20 countries can focus on taking proactive steps to balance economic growth in sustainable development towards reducing CO2 emissions and promoting renewable energy consumption.

5.3 Limitations and Future Research

The research limitations of this study pertain to the G20 countries, namely Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the UK, the USA, and the EU. This is because each of these countries has unique reporting standards and macroeconomic variables, which may only partially reveal certain sector-specific phenomena, dynamics, or the impact of renewable energy technology in these countries. Furthermore, while the Panel VAR approach can still analyze dynamic interrelationships between CO2 emissions and renewable energy consumption on economic growth, this research approach must fully consider more relevant impacts. For instance, G20 countries should implement a strategy to transition from fossil fuels to renewable energy. In addition, the data used is likely historical, so it needs to fully capture the growth of renewable energy technology or policies in G20 countries.

Besides, future research can overcome limitations in several stages, including strategies for improving quality and consistency for all G20 countries. This proves that G20 countries can collaborate with various international organizations or institutions to standardize data collection practices and implement more sophisticated data analysis techniques. This will allow them to compare data from multiple sources with improved data quality, resulting in a more accurate analysis. Using the VAR Panel Approach, the study examines the dynamic interrelationship between CO2 emissions, renewable energy consumption, and economic growth in G20 countries. Further research could include or replace the dependent variable with the independent variable, or vice versa, and provide information on technological innovation and policy actions that can mitigate economic growth.

Furthermore, it is crucial to explore energy and non-energy variables that have yet to receive much attention, such as technological innovation, emission taxes, and the presence of tangible measures that can alleviate change without compromising economic growth in G20 countries.
On the other hand, it is possible to incorporate several additional energy variables into the equation model better to understand their influence in a broader research area. Future research could provide policy solutions tailored to the unique economic conditions and situations of each G20 country. In terms of methodology, research should explore more sophisticated econometric techniques that can overcome the limitations of panel variance analysis. Additionally, it can conduct a comprehensive analysis of the G20 group and other countries, such as the OIC

countries, GCC countries, D-8 countries, Visegrad countries, Scandinavian countries, ASEAN countries, etc., using Panel Data VAR.

In addition, this allows you to see the short—and long-term dynamic interrelationships between one variable and another. Finally, future researchers can overcome this study's limitations by improving data quality, using new variables, expanding the scope of the most recent years, using excellent methodology, and performing a more comprehensive comparative analysis. This will ensure that future research is highly beneficial and significantly contributes to understanding and policies appropriate to conditions and circumstances. Lastly, Our study did not include the whole EKC theory in our research model because we omitted GDP^2 as an independent variable. In future studies, we recommend using GDP^2 as an independent variable.

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APPENDIX

Descriptive Statistics

	GDP (US$ Current)	C02 (Metric Tons)	REC (Annual %)	TO (Annual %)	URB (Annual %)	FDI (Annual %)
Mean	20248.71	7.997175	14.52913	49.81918	71.84829	1.968925
Median	15844.63	7.491583	9.780000	49.36433	76.87900	1.613738
Maximum	76329.58	20.46980	59.18000	110.5771	92.34700	12.73150
Minimum	301.5008	0.647451	0.010000	13.75305	25.54700	-3.606928
Std. Dev.	16746.16	5.084335	13.82813	19.10887	15.73595	1.821554
Skewness	0.684655	0.561330	1.372940	0.368552	-1.469760	1.772771
Kurtosis	2.503062	2.410995	3.947050	2.822823	4.461099	8.926312
Jarque-Bera	58.35378	44.20050	232.0109	15.80465	296.3286	1311.531
Probability	0.000000	0.000000	0.000000	0.000370	0.000000	0.000000
Sum	13364150	5278.135	9589.223	32880.66	47419.87	1299.490
Sum Sq. Dev.	18480584	17035.46	126012.2	240633.1	163181.6	2186.600
Observations	660	660	660	660	660	660

Correlation Matrix

	GDP	C02	REC	TO	URB	FDI
GDP	1.000000					
C02	0.597875	1.000000				
REC	-0.400634	-0.584341	1.000000			
TO	0.157682	0.152377	-0.244387	1.000000		
URB	0.527459	0.493778	-0.590097	0.080786	1.000000	
FDI	0.106194	0.049251	0.006137	0.166975	0.084849	1.000000

Unit Root Test Results by Levin, Lin, Chu (LLC) Test

At level

Test Types		**LogGDP**	**LogC02**	**REC**	**TO**	**URB**	**FDI**
C	t-Statistic	-1.32328	-3.48356	-2.41274	-0.75137	-3.63777	-4.73921
	Prob	(0.0929)	(0.0002)***	(0.0079)	(0.2262)	(0.0001)***	(0.0000)***
CT	t-Statistic	27.0803	3.03933	6.29011	-3.61777	-3.71834	-4.59515
	Prob	(0.9408)	(0.9988)	(1.0000)	(0.0001)***	(0.0001)***	(0.0000)***

First Difference

Test Types		**LogGDP**	**LogC02**	**REC**	**TO**	**URB**	**FDI**
C	t-Statistic	-12.3140	-6.48463	-5.27667	-15.7141	-19.4963	-12.5455
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
CT	t-Statistic	-10.3605	-4.63727	-3.09542	-13.4165	-50.6596	-9.63102
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Source: Author's computation; ***Notes:*** *(*) Significant at 1%; (**) Significant at 5%; (***) Significant at 10% and (no) Not Significant.*

Source: *Author's Computation.*

Unit Root Test Results by Augmented Dickey-Fuller (ADF)

At level

Test Types		**LogGDP**	**LogC02**	**REC**	**TO**	**URB**	**FDI**
C	t-Statistic	25.5225	53.8997	47.3256	41.7573	66.2727	103.605
	Prob	(0.9635)	(0.0699)	(0.1984)	(0.3943)	(0.0056)	(0.0000)***
CT	t-Statistic	31.0723	33.1197	28.2962	112.436	269.525	81.9453

	Prob	(0.8432)	(0.7711)	(0.9173)	(0.0000)***	(0.0000)***	(0.0001)***

First Difference

Test Types		LogGDP	LogC02	REC	TO	URB	FDI
C	t-Statistic	221.840	148.081	163.554	271.069	46.9755	334.988
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.2083)	(0.0000)***
CT	t-Statistic	162.889	114.905	133.154	445.586	289.251	274.364
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Source: Author's computation; ***Notes:*** *(*) Significant at 1%; (**) Significant at 5%; (***) Significant at 10% and (no) Not Significant.*
Source: *Author's Computation.*

Unit Root Test Results by Phillips-Perron (PP) Test
At level

Test Types		LogGDP	LogC02	REC	TO	URB	FDI
C	t-Statistic	28.3545	61.6151	52.4987	37.7935	164.931	142.318
	Prob	(0.9160)	(0.0156)	(0.0891)	(0.5700)	(0.0000)***	(0.0000)***
CT	t-Statistic	27.0803	24.7805	32.5174	66.0601	309.642	126.900
	Prob	(0.9408)	(0.9717)	(0.7937)	(0.0059)	(0.0000)***	(0.0000)***

First Difference

Test Types		LogGDP	LogC02	REC	TO	URB	FDI
C	t-Statistic	311.753	405.745	422.716	382.745	78.0900	543.659
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0003)***	(0.0000)***
CT	t-Statistic	295.160	423.513	718.442	448.692	523.321	2519.33
	Prob	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Source: Author's computation; ***Notes:*** *(*) Significant at 1%; (**) Significant at 5%; (***) Significant at 10% and (no) Not Significant.*
Source: *Author's Computation.*

Lag Order Criteria Test Results for VAR Model

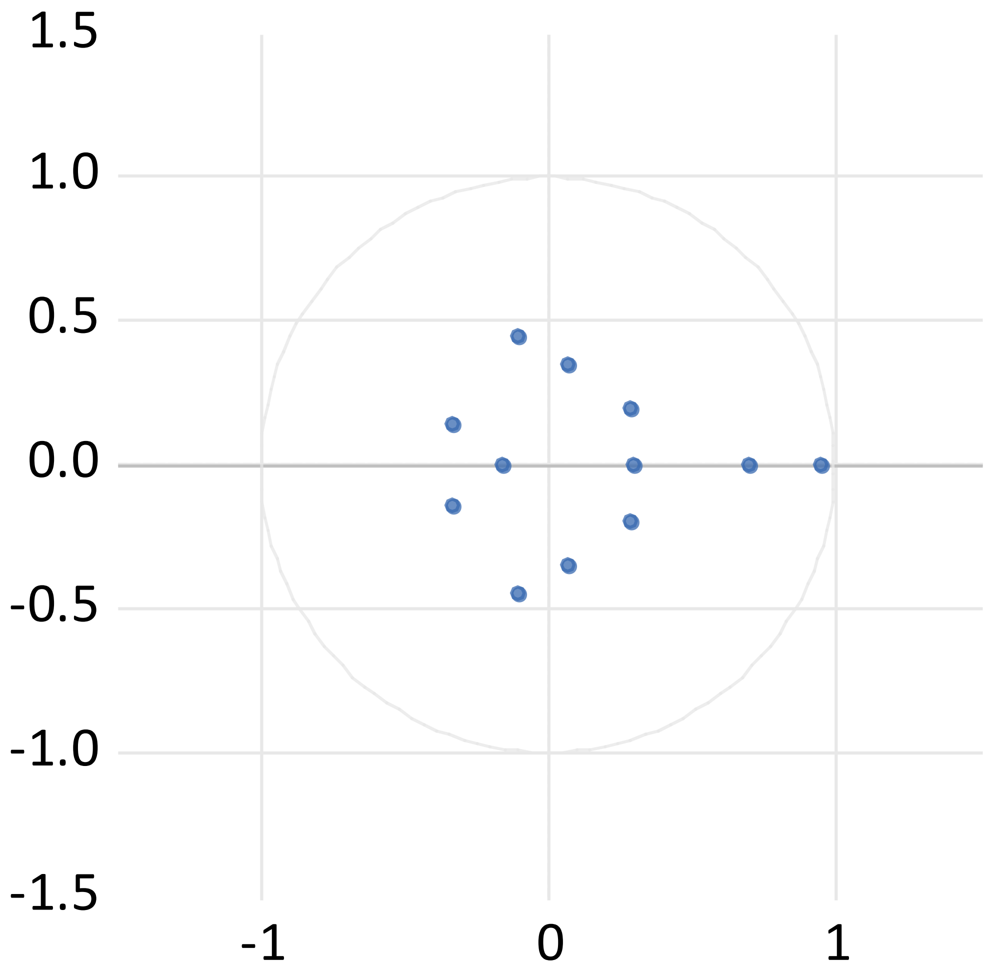
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-2520.70526570187	NA	0.000669	9.718097	9.767180	9.737325
1	-1645.497438056501	1726.852	2.65e-05	6.490375	6.833953*	6.624968
2	-1576.429875621798	134.6817	2.34e-05*	6.363192*	7.001266	6.613150*
3	-1556.812833428653	37.80053	2.49e-05	6.426203	7.358773	6.791527
4	-1540.580160073964	30.90451	2.69e-05	6.502231	7.729297	6.982920
5	-1507.937476389983	61.39336*	2.72e-05	6.515144	8.036706	7.111198
6	-1482.632878260947	47.00816	2.84e-05	6.556280	8.372338	7.267700

Note: ** indicates lag order selected by the criterion: LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion*

Source: *Author's Computation*

Roots of Characteristic Polynomial	
Endogenous variables: D(LOG_GDP)	
D(LOG_C02) D(REC) D(TO) D(URB)	
FDI	
Exogenous variables: C	
Lag specification: 1 2	
Date: 07/27/24 Time: 17:24	
Root	Modulus
0.946719	0.946719
0.696213	0.696213
-0.103689 - 0.444138i	0.456081
-0.103689 + 0.444138i	0.456081
-0.327527 - 0.139306i	0.355921
-0.327527 + 0.139306i	0.355922
0.068459 - 0.348372i	0.355034
0.068459 + 0.348372i	0.355034
0.288359 - 0.191097i	0.345932
0.288359 + 0.191097i	0.345931
0.293556	0.293556
-0.162378	0.162378
No root lies outside the unit circle.	
VAR satisfies the stability condition.	

Inverse Roots of AR Characteristic Polynomial



Cointegration Test *Result*

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob	Fisher Stat.* (frm max-eigen test)	Prob.
None	572.2	0.0000	320.4	0.0000
At most 1	276.0	0.0000	138.9	0.0000
At most 2	163.9	0.0000	90.70	0.0000
At most 3	100.5	0.0000	54.61	0.0616
At most 4	78.47	0.0000	56.30	0.0452
At most 5	85.76	0.0000	85.76	0.0000

Note: *Trace test indicates 6 cointegrating eqn(s) at the 0.05 level, * denotes rejection of the hypothesis at the 0.05 level*
***MacKinnon-Haug-Michelis (1999) p-values*

Granger Causality Test Result

Null Hypothesis:	Obs	F-Statistic	Prob.
LOG_C02 does not Granger Cause LOG_GDP	620	3.01639	0.0497*
LOG_GDP does not Granger Cause LOG_C02		3.19169	0.0418*
REC does not Granger Cause LOG_GDP	620	2.03686	0.1313
LOG_GDP does not Granger Cause REC		1.28536	0.2773
TO does not Granger Cause LOG_GDP	620	1.51237	0.2212
LOG_GDP does not Granger Cause TO		0.45377	0.6354
URB does not Granger Cause LOG_GDP	620	0.83892	0.4327
LOG_GDP does not Granger Cause URB		1.63656	0.1955
FDI does not Granger Cause LOG_GDP	620	0.32604	0.7219
LOG_GDP does not Granger Cause FDI		0.6198	0.5383
REC does not Granger Cause LOG_C02	620	2.63997	0.0722
LOG_C02 does not Granger Cause REC		1.10146	0.3330
TO does not Granger Cause LOG_C02	620	0.57728	0.5617
LOG_C02 does not Granger Cause TO		3.00374	0.0503
URB does not Granger Cause LOG_C02	620	2.77328	0.0632
LOG_C02 does not Granger Cause URB		0.20971	0.8109
FDI does not Granger Cause LOG_C02	620	0.63312	0.5313
LOG_C02 does not Granger Cause FDI		0.03235	0.9682
TO does not Granger Cause REC	620	0.62075	0.5379
REC does not Granger Cause TO		3.79198	0.0231*
URB does not Granger Cause REC	620	0.99724	0.3695
REC does not Granger Cause URB		0.21889	0.8035
FDI does not Granger Cause REC	620	1.07907	0.3406
REC does not Granger Cause FDI		0.25461	0.7752
URB does not Granger Cause TO	620	0.31661	0.7287
TO does not Granger Cause URB		1.10220	0.3328
FDI does not Granger Cause TO	620	1.75535	0.1737
TO does not Granger Cause FDI		0.25780	0.7728
FDI does not Granger Cause URB	620	1.07308	0.3426
URB does not Granger Cause FDI		0.24420	0.7834

Source: *Author's Computation.*

Note: *The asterisk (*) shows the null hypothesis is rejected*

VAR Estimation Results

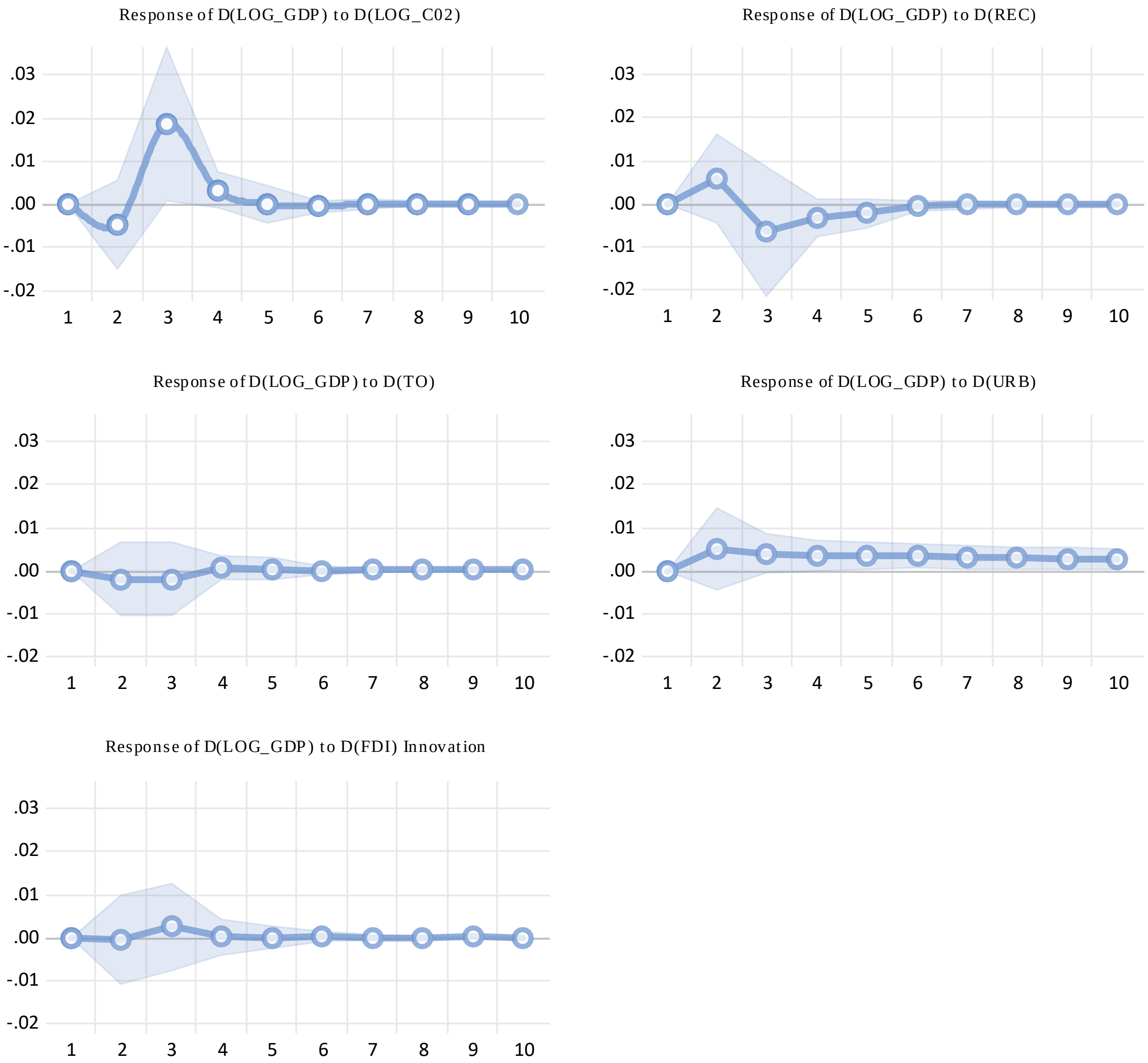
	D(LOG_GDP)	D(LOG_C02)	D(REC)	D(TO)	D(URB)	D(FDI)
D(LOG_GDP(-1))	0.137613	0.024907	-0.404293	0.952907	-0.016986	0.253147
	(0.04448)*	(0.02279)*	(0.51948)	(1.70366)	(0.02370)*	(0.55647)
	[3.09389]	[1.09300]	[-0.77827]	[0.55933]	[-0.71671]	[0.45491]
D(LOG_GDP(-2))	-0.12611	-0.016443	0.182251	-3.479575	0.030947	1.471864
	(0.04695)	(0.02406)*	(0.54837)	(1.79842)	(0.02502)*	(0.58743)
	[-2.68607]	[-0.68356]	[0.33235]	[-1.93479]	[1.23690]	[2.50561]
D(LOG_C02(-1))	0.045390	-0.151286	2.666197	3.176402	0.009406	-1.797331
	(0.12653)	(0.06482)	(1.47775)	(4.84640)	(0.06742)	(1.58300)
	[0.35873]	[-2.33381]	[1.80422]	[0.65541]	[0.13951]	[-1.13540]
D(LOG_C02(-2))	0.174910	-0.017128	2.425883	-11.09351	0.003893	0.023291
	(0.172345)	(0.08830)	(2.01284)	(6.60124)	(0.09184)	(2.15619)
	[1.01489]	[-0.19398]	[1.20521]	[-1.68052]	[0.04239]	[0.01080]
D(REC(-1))	0.006477	-0.005986	0.130604	-0.315191	-0.001630	-0.105230
	(0.00539)*	(0.00276)*	(0.06296)	(0.20649)	(0.00287)*	(0.06745)
	[1.20144]	[-2.16726]	[2.07434]	[-1.52644]	[-0.56746]	[-1.56021]
D(REC(-2))	-0.007718	-0.008019	0.138634	0.218875	-0.001713	0.111351
	(0.00807)	(0.00413)*	(0.09421)	(0.30895)	(0.00430)*	(0.10091)
	[-0.95678]	[-1.94042]	[1.47161]	[0.70844]	[-0.39862]	[1.10342]
D(TO(-1))	-0.000429	-0.000363	0.003902	-0.199177	-0.000239	0.0047239
	(0.00093)*	(0.00048)*	(0.01090)*	(0.03573)	(0.00050)*	(0.01167)
	[-0.45999]	[-0.75870]	[0.35813]	[-5.57381]	[-0.48049]	[0.40469]
D(TO(-2))	-0.000542	-0.00038	0.005301	-0.189360	0.000880	0.007343
	(0.00096)*	(0.00049)*	(0.01121)	(0.03678)*	(0.00051)*	(0.01201)
	[-0.56481]	[-0.78814]	[0.47273]	[-5.14900]	[1.71923]	[0.61129]
D(URB(-1))	0.072136	0.018845	-0.802036	1.328086	1.223634	-0.074142
	(0.072067)	(0.03692)*	(0.84167)	(2.76031)	(0.03840)*	(0.90161)
	[1.00096]	[0.51041]	[-0.95291]	[0.48114]	[31.8645]	[-0.08223]
D(URB(-2))	-0.034977	0.002804	0.292429	-0.616278	-0.265043	0.027139

	(0.07129)	(0.03652)*	(0.83260)	(2.73057)	(0.03799)*	(0.891890)
	[-0.49063]	[0.07677]	[0.35122]	[-0.22570]	[-6.97711]	[0.03043]
D(FDI(-1))	-0.000381	0.001919	-0.031061	0.270113	8.394132	-0.382036
	(0.00329)*	(0.00169)	(0.03845)*	(0.12609	(0.00175)*	(0.04118)*
	[-0.11567]	[1.13784]	[-0.80791]	[2.14228]	[0.04785]	[-9.27625]
D(FDI(-2))	0.001723	0.001169	-0.02345	0.041966	0.000294	-0.192253
	(0.00342)*	(0.00175)*	(0.03990)*	(0.13084)	(0.00182)*	(0.04274)*
	[0.50424]	[0.66795]	[-0.58780]	[0.32073]	[0.16140]	[-4.49837]
C	0.025526	-0.002106	0.104908	0.791950	0.011464	0.004881
	(0.00818)	(0.00419)	(0.09551)	(0.31324)	(0.00436)	(0.10232)
	[3.12121]	[-0.50271]	[1.09835]	[2.52822]	[2.63065]	[0.04771]

Source: Author's computation; ***Notes:*** *(*) Significant at 1%; (**) Significant at 5%; (***) Significant at 10% and (no) Not Significant.*

Source: *Author's Computation.*

Response to logGDP to logC02 REC TO URB TO FDI



VAR Residuals