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# Exploring the Effects of Renewable Energy consumption and Global Uncertainty on Economic Growth: A Global Perspective

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# Abstract

This dissertation examines the relationships among global uncertainty, renewable energy consumption (REC), and economic growth across 88 countries from1997 to 2020. Utilizing a PVAR and fixed effects model, the study empirically investigates 3 hypotheses. First, it confirms that heightened uncertainty significantly diminishes economic growth. Second, the analysis reveals that the relationship between REC and GDP growth varies by income level and is contingent upon global uncertainty's level. For all countries and middle-income countries, the uncertainty affects the efficacy of changes in REC on growth. The results are insignificant for high and low-income countries. However, after delineating high and low uncertainty contexts, the study finds that in low uncertainty contexts, an increase in REC does not significantly associate with growth. Conversely, in high uncertainty contexts, changes in REC negatively correlate with economic growth. These findings contribute to the understanding of how global uncertainty and renewable energy transitions interact with economic growth, providing insights for policymakers aiming to promote sustainable development amidst uncertain global conditions.

# Keywords

World uncertainty index, Renewable energy consumption, Economic growth, Panel vector autoregressive (PVAR) model, Fixed effect model.

# Word Count: 20026

# Declaration of Authorship

1. I hereby declare that I have compiled this thesis using the listed literature and resources only.
2. I hereby declare that my thesis has not been used to gain any other academic title.
3. I fully agree to my work being used for study and scientific purposes.

Prague 31/07/2024 **Yimo Li**

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# Contents

# Introduction

Currently, Environmental factors have become a focal point and are now considered crucial in decision-making processes (Gara et al., 2023). This study aims to investigate whether renewable energy consumption impacts economic growth, and if such effects are intensified under global uncertainty. Specifically, it seeks to determine whether renewable energy consumption can mitigate some of the negative impacts that heightened uncertainty has on economic growth.

The continuously growing global demand for energy remains a significant concern for the International Energy Agency and the global economy. Energy shortages are a critical constraint on economic development. Moreover, the persistent increase in international energy demands is accompanied by issues such as oil price volatility, global warming, and pollution (Sweidan, 2021). The close linkage between economic growth and energy consumption levels has always been recognized as a key element in discussions about economic expansion, resource scarcity, and environmental pollution (Alqaralleh and Hatemi-J., 2023). Hence, while oil and natural gas still play a crucial role in supporting growth, the focus is increasingly shifting towards the sustainable supply of energy resources, a prerequisite for countries' sustainable economic development. The consumption of renewable energy is garnering increasing attention (Cai and Wu, 2021; Alqaralleh and Hatemi-J., 2023).

There is a broad consensus among economists that uncertainty exerts a notable influence on the real economy (Liu and Gao, 2022 cited： He et al., 2020; Liang et al., 2021; Wen et al., 2021; Zeng et al., 2022). Existing research has confirmed that uncertainty significantly impacts GDP growth (Rehman et al., 2023). Higher levels of policy uncertainty are associated with a decline in GDP growth (Baker et al., 2016).

In recent decades, regions rich in oil resources, such as the Persian Gulf, have become some of the most geopolitical types of uncertain areas in the world. Significant geopolitical events, including the Gulf War, the invasion of Kuwait, and the invasion of Iraq, have all taken place in this region. Concurrently, the geopolitical implications of the natural gas standoff between Russia and Ukraine pose a challenge to global energy security. Moreover, other geopolitical events such as the 9/11 terrorist attacks, the Madrid bombings, the London bombings, nuclear tensions in Iran, the rise of ISIS, and the North Korean nuclear issue, have threatened economic stability. Resource-abundant countries occasionally employ their oil and gas resources as geopolitical leverage to pursue political objectives (Cai and Wu, 2021). Theoretically, high levels of global uncertainty should motivate countries to be self-sufficient, reduce reliance on foreign nations, and depend on their own renewable energy resources to mitigate the risks associated with the inflow of fossil fuels. Renewable energy, as an alternative to fossil fuels—namely oil, natural gas, and coal—has entered the energy market, reducing the adverse impacts of fossil fuel usage and its price volatility on the environment and economy (Sweidan, 2021).

Therefore, the issue of achieving energy autonomy using renewable energy becomes increasingly significant, as it appears to help reduce uncertainty (Flouros et al., 2022). This thesis enhances understanding of the intersection between renewable energy and uncertainty, offering insights for governments, energy planners, international organizations, and related institutions. These findings contribute to promoting economically and environmentally sustainable growth.

Overall, the research questions this paper exploring are:

1) Find the relationship between the World Uncertainty and EG for 88 countries. since there are few papers use WUI as the indicators of uncertainty to study the interrelationship between uncertainty and economic growth, it is reasonable to test

the relationship between the two variables before estimate they are negatively correlated.

2) Introduce REC in the model, check whether an increase in renewable energy consumption can offset the potential negative effects on economic growth caused by an increase in the World Uncertainty.

The following hypotheses are proposed:

**Hypothesis 1**: Economic growth decreases as uncertainty increases.

**Hypothesis 2:** The utilization of renewable energy is positively correlated with economic growth.

**Hypothesis 3(Joint test):** The level of uncertainty is a crucial factor influencing the extent to which renewable energy can benefit economic growth. Simultaneously, expanding the use of renewable energy can decrease uncertainty, thereby alleviating its adverse effects on economic growth.

However, the **hypothesis 3 is** based on the premise of utilizing domestic resources, which are not affected by fluctuations in international market, since:

1) If the introduction or expansion of renewable energy usage in the short term increases the dependence on imports (such as importing high-tech equipment and materials), this could conflict with the desired objectives of reducing uncertainty and enhancing economic stability.
2) Moreover, when a country's investment in renewable energy requires the import of many components (such as solar panels or wind turbines), this would lead to capital flowing(expenditure) from the domestic economy to the countries that manufacture these devices, such as China, India, or Thailand. The outflow of funds results in reduced investment in domestic production and could weaken the positive impact of the energy transition on domestic economic growth.

To evaluate the proposed questions and hypotheses, this article employs various econometric models. Given that the data used in this study are of a panel nature, four models are utilized and compared: Panel VAR model, the pooled model, fixed effects model, and random effects model. The empirical analysis is based on data from the World Bank and the WUI database. The study has excluded all countries and years with missing data

Researchers in the past have used multiple measures of uncertainty, including policy uncertainty (Baker et al., 2016), financial uncertainty (Choi, 2018), country-specific uncertainty (Bhattarai, Chatterjee, and Park, 2020; Hassan et al., 2020), and has investigated their influence on macroeconomic factors. Much of the existing academic paper primarily examines developed economies or high-income countries. While there are some studies on developing countries or emerging economies, such as Carriere-Swallow and Cespedes (2013), which investigated the effects of uncertainty shocks on macroeconomic variables using a vector autoregression framework, they found that uncertainty shocks notably reduced economic activity in emerging economies compared to the United States and other developed nations. Despite these findings, there remains a gap in research regarding the impact of global uncertainty on middle and low-income economies to address this gap, this article uses a large sample from 88 countries, encompassing high, middle, and low-income economies.

The study utilizes the World Uncertainty Index, developed by Ahir, Bloom, and Furceri (2018), as a measure of global uncertainty. This reflects various global uncertainties, such as terrorist attacks, pandemics, financial crises, debt crises, Brexit, and political crises. A panel regression model is utilized, covering annual data from 1996 to 2022, with no missing data. This thesis has constructed several groups of countries to investigate the research questions—one global panel comprising all 88 countries, three income-based panels (high-income, middle-income, and low-income countries), and oil export countries sub-group, as well as panels representing high uncertainty and low uncertainty scenarios.

The findings of this study make several contributions to the literature. Firstly, this thesis enriches the expanding body of research on the connection between global uncertainty and macroeconomic variables. While much of the research in this field has concentrated on developed economies, there are also a handful of studies exploring middle and low-income economies (Carriere-Swallow and Cespedes., 2013). By employing a global sample of 88 countries from 1996 to 2020, this research provides the most extensive empirical analyses in this area. And about world uncertainty and economic growth， normally they will construct measures of uncertainty, for example Lensink and Sterken (1999) incorporate export uncertainty, government policy uncertainty, and price uncertainty into an enhanced growth model, Nazari et al (2023)using production uncertainty and oil revenue uncertainty as the proxy for the uncertainty variable. Or they just focus on single one uncertainty like economic policy uncertainty or geopolitical risk (GPR) on economic growth. My research contributes to this field by introducing a variable for uncertainty—the WUI. The WUI is a newly released index in 2022, recently there are 3 studies have used it as indicator of uncertainty, for instance, Liu and Gao (2022) examined the stronger predictive power of the WUI on the U.S. GDP growth rate. Bannigidadmath et al (2024) studied Global Uncertainty and Economic Growth for Pandemic Periods.

Secondly, there has not been extensive research on how global uncertainty affects investments in renewable energy worldwide (Rehman et al., 2023). Previous studies have almost exclusively focused on the impact of a single type of uncertainty or risk on renewable energy, such as geopolitical danger, economic policy uncertainty, and climate policy uncertainty. However, Rehman et al. (2023) addresses this gap by simultaneously considering three significant global uncertainties - climate policy uncertainty, geopolitical risk, and economic policy uncertainty - and their impact on renewable energy. Guided by this, my thesis is the first to utilize the WUI to assess the impact on renewable energy consumption, incorporating the effects of various global risks (economic, financial, and political trends uncertainty). Consequently, this research aims to provide substantial insights into the existing gap in the literature concerning the impact of global uncertainty on the renewable energy index. By addressing this gap, the study will enhance our understanding of the intricate relationship between global uncertainty and renewable energy trends, offering valuable contributions to the field.

Thirdly, this paper make the empirical analysis of how the World Uncertainty Index and Renewable Energy Consumption interact and their collective impact on economic growth. While previous studies have independently examined the effects of uncertainty and renewable energy on growth, this research uniquely combine them together.

Finally, this paper first draws inspiration from the study by Le and Nguyen (2019) and extends the Cobb-Douglas production function as the base model to analyze global uncertainty, renewable energy consumption and economic growth by using Fixed Effect model with annual data.

This thesis is organized into five main sections. The next section offers a comprehensive review of relevant literature in this research field addressed in this paper, highlighting theoretical and empirical insights from other scholars in the field. Following this, the second section details the data sources and methodology employed in this study. The fourth section presents the empirical findings, evaluates their practical implications, and provides policy recommendations. Section five examines the limitations of the current study and proposes avenues for future research. Finally, the concluding section summarizes the findings and offers concluding remarks.

# 1. Literature Review

## 1.1 World Uncertainty Indicators comparation

During extreme events or market turbulence, uncertainty significantly increases. Following the global financial crisis, uncertainty has become a focal point of recent research. Due to the lack of a standardized measure of uncertainty, past studies have employed various alternative indicators. Commonly used indicators include the World Uncertainty Index (WUI), Economic Policy Uncertainty (EPU), and Geopolitical Risk (GPR).

First of all, Economic Policy Uncertainty (EPU) is an index designed to measure the uncertainty in economic policy decision-making, developed by Scott R. Baker, Nicholas Bloom, and Steven J. Davis in 2016. The EPU index aims to study the evolution of economic policy uncertainty since 1985 by analyzing the frequency of newspaper articles that discuss economic uncertainty related to policy.

The construction of the EPU index involves analyzing reports from 10 major U.S. newspapers. Articles are included in the EPU index if they contain terms related to the economy, uncertainty, and policy, such as "economic" or "economy," "uncertain" or "uncertainty," and "Congress," "deficit," "Federal Reserve," "legislation," "regulation," or "White House." This text-based approach captures the uncertainty surrounding economic policy decisions, including the decision-makers, the nature and timing of the decisions, and their potential economic impacts (Baker et al., 2016).

The EPU index addresses both short-term issues, such as when the Federal Reserve might adjust policy rates, and long-term issues, like the funding of welfare programs. Additionally, it considers non-economic policy issues, such as military actions, and their potential economic impacts. This comprehensiveness allows the EPU index to reflect a broad range of economic policy uncertainties, not just those within the economic domain (Baker et al., 2016).

The volatility of the EPU index is closely linked to major political events. For instance, significant increases in the EPU index have been observed during presidential elections, the Gulf War, the 9/11 terrorist attacks, and the 2011 debt ceiling dispute (Baker et al., 2016).

The EPU index extends across three dimensions: time (tracing back to 1900), cross-national (covering 11 countries, including all G10 economies), and specific policy categories. This multidimensional analysis provides researchers with a comprehensive perspective to observe and understand policy uncertainty (Baker et al., 2016).

The validity of the EPU index is supported by various forms of evidence. These include manual readings of 12,000 newspaper articles and comparative analyses of the EPU index with other economic uncertainty indicators, such as implied stock market volatility, and policy uncertainty indicators, like the frequency of policy uncertainty mentions in the Federal Reserve's Beige Book. Moreover, EPU indices constructed from newspapers with different political leanings show similar trends, further validating the reliability of the EPU index (Baker et al., 2016).

At the macroeconomic level, increases in the EPU index typically forecast declines in investment, output, and employment in the United States and 12 other major economies. This indicates that policy uncertainty has a significant negative impact on economic activity. Overall, the EPU index is an innovative, multidimensional, and validated tool for measuring economic policy uncertainty

Secondly, The Geopolitical Risk Index (GRP), developed by Dario Caldara and Matteo Iacoviello (2024), is a measure designed to quantify adverse geopolitical events and their associated risks. The GRP index is constructed by analyzing the frequency of mentions of geopolitical tensions in newspaper reports.

The scope of the GRP index is extensive, covering its evolution and economic impact since 1900. Through this approach, researchers can observe how geopolitical risks are closely related to economic indicators such as investment, stock prices, and employment levels. When geopolitical risk increases, these economic indicators tend to decline, indicating the negative impact of geopolitical events on economic activity (Caldara and Iacoviello, 2024).

The peaks of the GRP index occur at key historical moments, such as the periods surrounding the two World Wars, the onset of the Korean War, the Cuban Missile Crisis, and the aftermath of the 9/11 terrorist attacks. During these times, heightened geopolitical tensions significantly negatively impacted the global economy, increasing the likelihood of economic crises and posing substantial downside risks (Caldara and Iacoviello, 2024).

To construct the GRP index, researchers utilized different newspaper sources and time periods. The recent GRP index is based on data from 10 newspapers since 1985, while the historical index uses data from 3 newspapers starting from 1900. Additionally, the researchers developed country-specific GRP indices for 44 different nations. This cross-national analysis provides valuable insights into the specific impacts of geopolitical risk in different countries and regions, helping to reveal the sensitivity and vulnerability of various countries to geopolitical events (Caldara and Iacoviello, 2024).

Thirdly, The World Uncertainty Index (WUI) is a measure of global uncertainty introduced by Ahir, Bloom, and Furceri. The WUI aims to capture and quantify global uncertainty, including but not limited to geopolitical risks (GPR), terrorist attacks, epidemics, financial crises, debt crises, and political crises (Ahir, 2022).

The construction of the WUI is based on the frequency of the term "uncertainty" and its variants in the quarterly country reports of the Economist Intelligence Unit (EIU). Since 1996, the WUI has covered 143 countries, accounting for the total word count of each report to ensure consistency and comparability of the measure. These reports are compiled by in-country experts and a network of country specialists with at least 5-7 years of relevant experience, ensuring the depth and breadth of the reports (Ahir, 2023). The EIU's quarterly country reports encompass both economic and political aspects. The economic section includes recent developments, key government policies, and short- and medium-term forecasts, covering economic growth, inflation, monetary and fiscal policies, exchange rates, and external sector dynamics. The political section examines political stability, election processes, and international relations (Ahir, 2022). Since 1952, the WUI has been constructed quarterly for 143 countries, covering both developed and developing nations, with data traceable back to the 1950s. Analysis of the WUI reveals that uncertainty levels are higher in developing countries, while developed economies, due to closer trade and financial linkages, exhibit more synchronized uncertainties (Ahir, 2022).

To ensure the accuracy and reliability of the WUI, researchers have evaluated it through various methods, including narrative studies related to global peak events, correlation analysis with Economic Policy Uncertainty (EPU), stock market volatility, forecast disagreements, and market usage validation. The WUI has been adopted by commercial data providers such as Bloomberg, FRED, Haver, and Reuters, meeting the needs of banks, hedge funds, corporations, and policymakers. Over the past three decades, peaks in the WUI correspond to significant events such as the 9/11 attacks, the Gulf War, the collapse of Lehman Brothers, the Eurozone debt crisis, the Brexit referendum, the 2016 U.S. presidential election, U.S.-China trade tensions, and the COVID-19 pandemic (Ahir, 2022).

In comparing the three commonly used indicators, this paper selects the World Uncertainty Index (WUI) as the measure of global uncertainty. The advantage of the WUI lies in the stability and reliability of its data sources, which are derived from the quarterly country reports of the Economist Intelligence Unit (EIU). These reports are compiled by in-country experts and a network of country specialists with 5-7 years of experience, ensuring the quality and consistency of the data. While the Global Policy Uncertainty Index (GPR) and the Economic Policy Uncertainty Index (EPU) demonstrate sensitivity in capturing uncertainties related to specific events, they rely on the frequency of newspaper reports and may be influenced by media attention shifts and reporting cycles, resulting in greater data volatility.

Compared to the GPR and EPU, the WUI covers 143 countries since 1952, providing a longer-term historical perspective that is beneficial for analyzing long-term trends and the impacts of uncertainty. Another significant advantage of the WUI is its global applicability; it encompasses both developed and developing countries, offering a more comprehensive view of global uncertainty.

Despite potential subjectivity in the WUI, its accuracy and reliability have been demonstrated through narrative studies related to global peak events, correlation analysis with economic indicators, and market usage validation. Therefore, considering the stability, reliability, global coverage, and long-term data advantages of the WUI, this paper adopts the WUI as the primary indicator for analyzing global uncertainty. This choice will enable the study to more accurately capture and assess the impact of uncertainty on the global economy and renewable energy consumption, providing valuable insights for policymakers and market participants.

## 1.2 Primary Relationships

### 1.2.1 World uncertainty and Economic Growth

Since the onset of the global financial crisis, there has been growing global concern over worldwide uncertainty. Businesses and investors generally prefer stable, low-risk environments conducive to economic growth (Annastiina, 2024). In recent years, global uncertainty has intensified, notably due to events such as the COVID-19 pandemic, the Russia-Ukraine conflict, and the Israel-Palestine tensions, exacerbating the situation. Reports from the International Monetary Fund in 2017 highlight uncertainty as a significant factor contributing to the economic challenges faced by economies like South Africa, the United Kingdom, and the United States (Bannigidadmath et al., 2024). During the COVID-19 crisis, the pandemic led to a sharp decline in global economic growth, with global Gross Domestic Product (GDP) falling by 3.4% in 2020, reaching $84.9 trillion in the same year. This indicates that the 3.4% decrease in economic growth resulted in economic output losses exceeding $2 trillion (Statista,2024). However, it is worth noting that the impact of the pandemic, as an uncertain factor, on the global economy has been uneven across different countries and regions. For example, in the third quarter of 2020, China recorded a GDP growth rate of nearly 5%, whereas the United Kingdom experienced a decline of nearly 8%. However, by the same quarter of the following year, the UK had rebounded with a growth of approximately 7%. In Asia, the range of GDP variation spanned from 0.2% in East Asia to -7.7% in South Asia (Statista,2024). For example, in 2020, Indonesia's GDP contracted by 2.07%, marking its largest decline since the Asian financial crisis. For OECD countries, in the second quarter of 2020, the real GDP decreased by 9.8%, the largest drop ever recorded in the OECD countries (Bannigidadmath et al., 2024).

Regarding the Russia-Ukraine war, beyond the devastating human casualties, the war has had catastrophic economic impacts on Ukraine itself, as well as significant repercussions for the European Union (EU) and the entire world. In the European Union (EU), the economic recovery post-COVID-19 has encountered unexpected delays, primarily attributed to the ongoing Ukraine war. According to the European Commission's Autumn 2021 forecast, the EU's gross domestic product (GDP) was projected to expand by 4.3% in 2022 and by 2.5% in 2023. However, geopolitical tensions, particularly from the Ukraine conflict, have hindered the pace of recovery, leading to cautious economic outlooks across the region. However, the actual growth in 2022 was 3.5%, and the estimated growth for 2023 is 0.5%. Moreover, the European Union (EU) faced a significant energy and cost-of-living crisis in 2022, the reverberations of which continue to impact the region. Data from the World Bank indicates that Russia's GDP contracted by 2.1% in the same year (Annastiina, 2024).

Regarding the Israel-Hamas conflict, firstly, the clashes between Israel and Hamas have heightened regional tensions, suggesting a potential escalation in the area. Businesses and investors typically prefer operating in stable, low-risk environments (Annastiina, 2024). As a result, regional conflicts directly influence investor expectations and have a detrimental impact on economic growth. Furthermore, heightened regional tensions leading to displacement and casualties on both sides exacerbate these factors, further impeding economic growth. Nonetheless, Israel's GDP showed an increase in the second quarter of 2023 (Yoganandham, 2023). Thirdly, the escalation of the Israel-Hamas war poses risks to the global economy, potentially undermining interdependence and affecting globalization, thereby adversely impacting economic growth. Some economists argue that the processes of 'delocalization' have slowed or even reversed, influenced by factors such as the trade war between the United States and China, the COVID-19 pandemic, and Russia's invasion of Ukraine. Wells Fargo economists predict that war and stricter trade barriers will hinder globalization. They contend that this conflict could lead to a reduction in trade cooperation, information sharing, technology exchange, and financial market connectivity, all of which could fracture economic linkages. The extent of the war's impact depends on the degree of division in the Middle East. Furthermore, U.S. support for Israel might deteriorate trade relations with China, accelerating de-globalization, triggering inflation, and tightening monetary policy, all of which could reduce global competitiveness and GDP growth (Yoganandham, 2023). In January 2023, the International Monetary Fund (IMF) highlighted that 'global economic uncertainty remains persistently high, exerting pressure on economic growth.' Since then, rather than diminishing, this uncertainty has continued unabated, posing ongoing challenges to global economic stability and growth prospects, as noted by Annastiina (2024). In summary, understanding how global uncertainty impacts macroeconomic growth is crucial.

This study is driven by theoretical work suggesting that uncertainty influences investment decisions, thereby impacting economic growth. As early as 1983, Bernanke's research indicated that uncertainty affects growth and investment. Nevertheless, the connection between corporate investment and uncertainty remains ambiguous. One school of thought suggests that uncertainty can stimulate investment. Knight's (1921) seminal theory underscores that entrepreneurs possess the acumen to identify and capitalize on investment opportunities amidst uncertainty, thereby generating profits through efficient resource allocation. Consequently, uncertainty is regarded as a catalyst for corporate profitability. Moreover, under specific conditions—namely, perfect competition, constant returns to scale, and symmetrical adjustment costs—economic frameworks articulated by Hartman (1972) and Abel (1983) illustrate that heightened uncertainty may enhance the anticipated returns on capital, thereby encouraging increased investment. Empirical evidence supporting this assertion is provided by Abel and Blanchard (1986).

Conversely, when the assumptions proposed by Hartman (1972) and Abel (1983) are not taken into account, Caballero (1991) uncovered that an increase in uncertainty actually results in a decrease in capital investment. This suggests that without the conditions of perfect competition, constant returns to scale, and symmetric adjustment costs, the heightened uncertainty negatively impacts the propensity for businesses to invest in capital. Bloom, Bond, and Van Reenen (2007) observed similar findings under the framework of irreversible investments. Because of the (partial) irreversibility of investments, increased levels of uncertainty diminish the sensitivity of investment decisions to changes in demand. This phenomenon occurs because the irreversible nature of investments makes firms more cautious, leading them to delay or reduce their investment activities in response to demand shocks when faced with heightened uncertainty. Uncertainty enhances the value of real options, causing firms to exercise greater caution when making investment or disinvestment decisions. For instance, during times of elevated uncertainty, such as the aftermath of the 1973 oil crisis, firms tend to exhibit significantly reduced responsiveness to targeted policy measures. The irreversibility or sunk costs associated with investment projects compel firms to balance the profit differential between current and future investments. The higher the level of uncertainty, the greater the potential returns from delaying investment, thereby increasing the value of waiting; consequently, companies reduce current investment expenditures (Wang et al., 2014).

Policy uncertainty, being a specific type of uncertainty, has a profound effect on corporate investment decisions. This form of uncertainty undermines the perceived value of market protections offered by the government, increases anticipated costs, and consequently leads to a reduction in both long-term investments and overall output. Wang et al. (2014) highlight that the unpredictability associated with policy changes discourages firms from committing to substantial, long-term investments due to the heightened risk and potential for unfavorable economic conditions. Entrepreneurs rationally refrain from increasing investments during periods of policy changes until the uncertainties associated with policy reforms are resolved and policy stability is achieved (Rodrik, 1991). Research by Julio and Yook (2012) revealed that corporate investment declines by an average of 4.8% during election years compared to the years without election. This indicates that the uncertainty surrounding elections leads firms to adopt a more cautious investment approach. Additionally, Gulen and Ion (2013), leveraging the Economic Policy Uncertainty Index created by Baker et al. (2013), found that elevated levels of economic policy uncertainty significantly curb corporate investment activities. These findings, as referenced by Wang et al. (2014), underscore the detrimental impact that uncertainty, particularly related to economic policies and political events, can have on corporate investment decisions.

In their 2014 study, Wang et al. investigated the influence of economic policy uncertainty on the investment behavior of Chinese listed companies. Their research findings suggest that, in general, firms tend to decrease their investment activities during times of elevated economic policy uncertainty and conversely, increase investment when uncertainty is low. However, companies that achieve higher returns on investment capital and those that primarily depend on internal financing are better positioned to counteract the adverse effects of policy uncertainty on their investment activities. These firms can more effectively navigate periods of uncertainty due to their robust financial performance and reduced reliance on external funding sources. Furthermore, businesses located in regions with a higher degree of marketization exhibit greater sensitivity to economic policy uncertainty. This heightened responsiveness is due to the more competitive and dynamic market environments in these areas, which make them more susceptible to policy fluctuations. For instance, compared to mature market economies, transitioning economies often experience higher returns on investment capital, lower degrees of marketization (more planning-oriented), and less developed financial systems (more reliant on internal financing). Higher returns on investment capital may incentivize firms to continue investing rather than delay investment amidst greater policy uncertainty. Greater planning and reliance on internal financing suggest that firms might be less adversely affected by policy uncertainty. For example, the countries least affected by the 2007 financial crisis were emerging economies rather than developed ones, including China, Brazil, Romania, Armenia, and the United Arab Emirates. Therefore, the detrimental effect of economic policy uncertainty on corporate investment is comparatively less pronounced in these types of economies than in mature market economies. In emerging or transitioning economies, the influence of policy uncertainty is somewhat mitigated, possibly due to different economic structures, growth trajectories, or the presence of alternative investment opportunities that are less sensitive to policy fluctuations. Consequently, it is meaningful to distinguish and analyze countries with different levels of development, which will be further discussed in the subsequent sections of this paper.

Moreover, uncertainty affects household total expenditure, thereby influencing the macroeconomy. Caballero (1990) observed that uncertainty can induce households to curtail spending as individuals become apprehensive about future income stability, prompting them to adopt precautionary measures.

Third, the impact of uncertainty on economic growth varies depending on the country context. Carrière-Swallow and Céspedes (2013) utilized a vector autoregression framework to analyze a diverse sample of economies, encompassing both developed and emerging markets. Their study revealed considerable variability in how investment and private consumption respond to shocks in global uncertainty. Specifically, they observed that uncertainty shocks precipitated a marked downturn in economic activity within emerging economies compare to the responses seen in the United States and other advanced economies. Building on Baker et al. (2012), Scheffel (2016) developed an alternative indicator for political uncertainty (PU) and investigated its dynamic effects on the U.S. economy. The study revealed that political uncertainty shocks have a pervasive impact on the dynamic evolution of the U.S. economy, with this effect being more pronounced in highly globalized markets compared to other measures of actual economic activity (Bannigidadmath et al., 2024). Cuaresma et al. (2019) conducted a study on the macroeconomic impacts of international uncertainty shocks across G7 countries, revealing significant effects on the economic activities of all economies in the group.

Finally, Belke and Osowski (2019) investigated the spillover effects of economic policy uncertainty shocks from the U.S. and the Eurozone on third countries, finding that increases in economic policy uncertainty have a strong negative impact on GDP. The economic downturn on the European continent (excluding Germany) is more severe than in Anglo-Saxon countries due to uncertainty shocks, with U.S. uncertainty shocks having a greater impact than those from the Eurozone. Economic policy uncertainty affects not only the country experiencing the shock but also has significant cross-border effects. According to Bobasu et al. (2023), global uncertainty shocks significantly influence economic activity fluctuations in the Eurozone, with a one standard deviation increase in these shocks correlating with a reduction of approximately 0.12 percentage points in Eurozone industrial production within a three-month period. Bannigidadmath et al. (2024) found that during the pandemic, the World Uncertainty Index negatively impacted GDP growth rates over a one-year forecast horizon across six sectors: global, Asia-Pacific, Europe, Western

Hemisphere, advanced economies, and emerging economies. Moreover, the adverse impact of uncertainty on GDP growth rates was exacerbated during the pandemic. These findings underscore the importance of distinguishing between groups of countries at different stages of development for comparative analysis, which will be further explored in this paper.

Regarding geopolitical risks, the findings are basically the same. Gaibulloe and Sandler (2008) demonstrated that both domestic and transnational terrorism negatively impact economic growth in 18 European countries. In their 2019 study, Soybilgen et al. discovered a noteworthy and inverse correlation between geopolitical risks and economic growth across 18 emerging countries over a span of three decades, specifically from 1986 to 2016. Their findings indicate that heightened geopolitical risks significantly hinder economic progress in these nations. It is important to emphasize that the disruptive effects of many geopolitical tensions may be localized but can have significant negative impacts on the macroeconomic situation of a country (Soltani et al., 2021). Soltani et al. (2021) identified a negative and significant effect of geopolitical risks on economic growth in MENA countries. Higher geopolitical risks lead to increased economic vulnerability in the Middle East and North Africa, where militaristic policies and the impacts of war hinder the development of specific economies, preventing them from attracting foreign investors and achieving economic growth.

### 1.2.2 Renewable energy consumption and Economic Growth

The relationship between energy consumption and economic growth can be elucidated through four hypotheses. The "growth hypothesis" posits that energy is a primary input source for the growth process, and energy is found to positively impact growth.

In this scenario, energy-saving policies would negatively affect economic growth (Bhattacharya et al., 2016). The 'feedback hypothesis' posits a positive feedback loop between economic growth and energy consumption, implying a bidirectional relationship where changes in energy consumption influence economic growth, and vice versa (Bhattacharya et al., 2016; Le, 2016). The 'neutrality hypothesis' suggests that there exists no discernible relationship between energy consumption and output, implying that economic growth and energy consumption are independent variables. On the other hand, the 'conservation hypothesis' posits that economic growth solely influences energy consumption, with no reciprocal effect, thereby making energy use restrictions a viable option in this scenario (Bhattacharya et al., 2016; Le, 2016).

Numerous previous studies in the field have explored the nexus between energy use and economic growth. However, given that this article specifically focuses on renewable energy consumption, thus not delving into overall energy consumption. Empirical investigations into the relationship between renewable energy use and real GDP growth remain limited. The existing literature can be divided into single-country studies and multi-country studies, and there is a variety of findings that lack a consensus regarding the existence or direction of causality between renewable energy consumption and economic growth. These studies produce differing conclusions, highlighting the complexity and variability of the relationship across different contexts (Ocal and Aslan, 2013). This variation arises due to differences in subjects, methodologies, and time series employed across studies.

Topcu et al. (2020) employed the panel vector autoregression (PVAR) method to examine the effects of energy consumption and total capital accumulation on economic growth across 124 countries/regions. Their results revealed varying conclusions for low-income, middle-income, and high-income country groups. Tugcu et al. (2012) conducted causality tests in G7 countries over the period 1980-2009, finding no causal relationship for France, Italy, Canada, and the United States, bidirectional causality for the United Kingdom and Japan, and unidirectional causality from economic growth (EG) to renewable energy consumption (REC) for Germany. Omri (2014) summarized that in studies examining the relationship between renewable energy utilization and economic growth, the neutrality hypothesis was supported by 40% of empirical investigations, the conservation hypothesis by another 40%, and the growth hypothesis by 20%.

In summary, as Ocal and Aslan concluded in their 2013 study, the research findings on the causal relationship between renewable energy consumption and economic growth exhibit variations and contradictions across different countries.

The findings regarding the 'growth hypothesis' are as follows: Ozcan and Ozturk (2019) conducted a study on the correlation between renewable energy consumption and economic growth across 17 emerging economies. Their research revealed that Poland was the sole country to substantiate the growth hypothesis, indicating variability in the extent to which renewable energy consumption positively influences economic growth among these nations. Doytch and Narayan (2021) studied the impact of non-renewable and renewable energy on economic growth, finding that renewable energy promoted the growth of the service sector in high-income and middle-income economies. Ivanovski et al. (2021) conducted an analysis of both OECD and non-OECD groups, uncovering that in non-OECD countries, both renewable and non-renewable energy sources contributed to economic growth. Conversely, in OECD countries, only non-renewable energy consumption positively influenced economic growth. Their study highlights the differing impacts of energy types on economic growth across these two groups of countries. In contrast, Wang and Wang (2020) identified a nonlinear association between renewable energy usage and economic growth in their analysis of OECD countries. Their findings indicated that an uptick in renewable energy consumption positively contributed to economic expansion.

It is noteworthy that Chen et al. (2020), basing the 103 countries' sample groups, conducted an in-depth study on the causal relationship between renewable energy use and economic growth. The research revealed that in developing or non-OECD countries, once renewable energy consumption surpasses a specific threshold, it exerts a positive influence on economic growth, supporting the growth hypothesis. However, if renewable energy consumption in developing countries falls below the given threshold level, its impact on economic growth is negative, aligning with the conservation hypothesis (Alqaralleh and Hatemi-J., 2023).

The empirical studies supporting other "conservative hypotheses" include research by Ocal and Aslan (2013), who investigated the correlation between renewable energy consumption and economic growth in Turkey. Their findings, utilizing the ARDL method, indicated a negative impact of renewable energy consumption on economic growth. Additionally, they observed a unidirectional causality from economic growth to renewable energy consumption.

Armeanu et al. (2017) discovered a unidirectional causality between renewable energy consumption and economic growth in their analysis of 28 EU countries from 2003 to 2014. Similarly, Rahman and Velayutham (2020) found a unidirectional causal relationship from economic growth to renewable energy consumption in their study of five South Asian countries. In another study, Bui Minh and Bui Van (2023) examined the relationship between renewable energy consumption and GDP in Vietnam, revealing evidence of a conservative effect. Their findings indicate a unidirectional causality from renewable energy consumption to economic growth, with this relationship enduring over the long term.

Kahia et al. (2017), Rafindadi and Ozturk (2017), and Gyimah (2022) demonstrated the feedback hypothesis in their studies, showing a bidirectional causality between renewable energy use and GDP (Bui Minh and Bui Van, 2023).

However, some empirical studies support the neutrality hypothesis, which posits that no causal relationship was found between the utilization of renewable energy and GDP. The empirical results of Payne (2008) and Menegaki (2011) indicate no causal relationship for the United States during the period from 1949 to 2006, and similarly, no causal relationship was found for the 27 EU countries. Payne (2009) explored the correlation between renewable and non-renewable energy consumption and economic growth spanning between 1949 and 2006 for United States of America. The findings indicated an absence of causality between renewable energy consumption and economic growth. In the context of emerging economies, Ozcan and Ozturk (2019) investigated the causal link between renewable energy usage and economic growth during the period from 1990 to 2016. Their analysis revealed no causal relationship between renewable energy consumption and economic growth across most countries, except for Poland. Maji et al. (2019) found that the situation in Spain also conforms to the neutrality hypothesis.

### 1.2.3 Renewable energy consumption and World uncertainty

Currently, empirical research has found both positive and negative correlations between uncertainty and renewable energy consumption. For example, regarding economic policy uncertainty, Wei et al. (2021) investigated the relationship between economic policy uncertainty and energy production in China from 1995 to 2019. They found that economic policy uncertainty could positively impact the progress of renewable energy consumption by altering supportive policies. In a similar vein, Chu and Le (2021) analyzed the interplay between economic policy uncertainty, energy intensity, and renewable energy consumption within the G7 countries. Their empirical findings indicate that economic policy uncertainty plays a positive role in promoting the advancement of renewable energy consumption.

On the other hand, Liu et al. (2020) investigated the influence of economic policy uncertainty on 52 energy firms in China. Their study concluded that heightened economic policy uncertainty substantially diminished investment in renewable energy companies. Similarly, Shafiullah et al. (2021) used monthly data from the United States to investigate the impact of economic policy uncertainty on renewable energy consumption. Their findings revealed that greater economic policy uncertainty significantly curtailed renewable energy consumption. Additionally, their analysis demonstrated a bidirectional causality between economic policy uncertainty and renewable energy consumption, indicating a reciprocal relationship between these variables. Sohail et al. (2021) studied the impact of economic policy uncertainty on renewable energy consumption in the BRIC countries, finding a negative correlation between economic policy uncertainty and renewable energy consumption.

Appiah-Otoo (2021) employed the Autoregressive Distributed Lag (ARDL) method to evaluate the influence of monetary policy uncertainty on renewable energy consumption in the United States, uncovering a significant but negative effect. Similarly, Yi et al. (2023) investigated the impact of economic policy uncertainty on renewable energy consumption across 20 countries, finding a negative but statistically insignificant correlation. Meanwhile, Liu et al. (2022) explored the spillover effects of economic uncertainty on the renewable energy market within the time-frequency domain. Their research indicated that heightened economic uncertainty intensifies the association between economic fluctuations and the renewable energy sector.

Furthermore, regarding global events such as pandemics, Hemrit and Benlagha (2021) reported that pandemic-induced uncertainty had a significant positive impact on the WilderHill New Energy Global Innovation Index (NEX), which is benchmarked to renewable energy. Similarly, Ji et al. (2018) showed that there was a negative dependence between uncertainties and renewable energy markets. Zhao et al. (2024) also support these findings.

Thirdly, for geopolitical risks and uncertainty, research on the impact of geopolitical risk on renewable energy markets is relatively scarce. Sweidan (2021), utilizing quarterly data from the United States and an Autoregressive Distributed Lag (ARDL) model, demonstrated that geopolitical risk positively influences renewable energy consumption. However, Su et al. (2020) found there is no causal relationship between geopolitical risk (GPR) and renewable energy consumption. Yang et al. (2021) provided evidence of asymmetric risk spillovers, concluding that the sensitivity to oil market volatility is lower than the downside risk for clean energy.

Zhao et al. (2024) found a significant relationship between renewable energy indices and both GPR and economic uncertainty indices (EUI). In the era of economic globalization, political and economic uncertainties have a significant impact on renewable energy indices. The advancement of renewable energy plays a crucial role in enhancing the energy independence of consuming nations and in reducing the adverse effects of such uncertainties. However, as risks escalate, the financial returns on renewable energy investments tend to decrease. Despite this, renewable energy demonstrates its value as a safe haven under varying market conditions, whether bearish, normal, or bullish, by offering protection against economic uncertainty and geopolitical risks. The relatively weak correlation between renewable energy indices and measures of geopolitical risk (GPR) or economic uncertainty indices (EUI) further supports the hedging properties of renewable energy during times of economic and geopolitical instability. Nonetheless, the renewable energy sector may encounter challenges such as short-term cost increases and supply chain disruptions, which can hinder its development (Zhao et al., 2024).

Thus, most studies find a negative correlation between economic policy uncertainty and renewable energy consumption. This may be due to several reasons:
Firstly, the energy sector tends to be highly sensitive to policy uncertainty, particularly regarding investments in renewable energy, which are a form of specific asset investment. Asset specificity refers to the value of an asset in alternative uses and underscores the unique nature of investments in renewable energy. In an environment with high asset specificity, the value of the investment in other uses is relatively low. Therefore, independent parties will suffer greater losses from adverse policy changes compared to situations where assets are relatively less specific (Hvelplund et al., 2019). Gulen and Ion (2016) provide evidence that policy uncertainty exerts a greater inhibitory effect on corporate investment for firms with irreversible investments. Wang et al. (2014) and Xie et al. (2019) explored how policy uncertainty impacts corporate investment in China, while Chen et al. (2020) investigated this effect on Australian firms. Alvarez et al. (1998) examined a broad sample of OECD countries, and Julio and Yook (2012) analyzed data from 48 countries, both concluding that policy uncertainty significantly hinders corporate capital investment. Bhattacharya et al. (2017) studied data from 43 countries, revealing that it is policy uncertainty, rather than the lack of policy, that negatively influences firms' innovation (Shafiullah et al., 2021).

Furthermore, policy stability is crucial for making long-term investment decisions. When a project's estimated net present value (NPV) is positive, investors are likely to allocate resources to that particular project. This mainly depends on two factors—

future cash flows and the discount rate. The projected future cash flows of a project are heavily influenced by the perceived risk of the project. Regulatory uncertainty complicates the task of decision-makers in evaluating the risks associated with cash flows (Shafiullah et al., 2021). Menegaki (2008) indicates that renewable energy investors use a discount rate much higher than the market discount rate when evaluating projects. A higher discount rate easily leads to economically viable projects being rejected (Shafiullah et al., 2021). Consequently, firms will not invest in such projects. Demir and Ersan (2017) illustrate that as economic policy uncertainty rises, firms in BRICS countries tend to increase their cash holdings (Shafiullah et al., 2021).

Thirdly, the increase in renewable energy usage might also contribute to policy stability through several indirect channels. For instance, Zhao et al. (2024) found that the development of renewable energy can significantly enhance the energy independence of consuming countries, thereby reducing the negative impacts of political and economic uncertainties. Furthermore, one of the main reasons for policy uncertainty can be attributed to debates over the economic viability of renewable energy. For example, in the United States, the coal industry has been heavily promoted under the guise of job creation and preventing the rapid decline of the coal industry (2019), or through actions such as withdrawing from the Paris Climate Agreement and repealing the Clean Power Plan. These changes are often driven by national politics and lobbying by the fossil fuel industry, which contend that the generation and utilization of renewable energy face uncertainty and economic disadvantages. Brulle's research in 2018 provides evidence that lobbying expenditures related to climate change legislation in the U.S. Congress amounted to approximately $2 billion between 2000 and 2016. This figure represents about 3.9% of the total lobbying expenditures during that period. Primary lobbyists included entities from the fossil fuel, transportation sectors, utilities, and associated trade groups, advocating for the introduction or repeal of substantial climate-related laws (Meng and Rode, 2019).

Therefore, once the penetration rate of renewable energy increases, the benefits of clean energy become more apparent. In this scenario, the uncertainty associated with energy usage is largely mitigated. Furthermore, the scaling up of renewable energy projects is anticipated to drive innovation and the widespread adoption of new technologies, thereby fostering economies of scale within the industry. This, in turn, will reduce the costs of renewable energy production and usage. Additionally, in such an environment, the effectiveness of lobbying efforts may diminish, potentially leading to greater policy stability. This suggests that as the high penetration of renewable energy brings about significant social benefits, the likelihood of policy-making instability is expected to decrease. Hence, a bidirectional negative relationship exists between policy uncertainty and the consumption of renewable energy (Shafiullah et al., 2021).

# 2. Methodology and Data

The empirical analysis utilizes data spanning from 1997 to 2020, covering a total of 88 countries[1]. The detection includes several primary country groups: (1) All 88 countries, (2) High-income countries, (3) Higher and lower middle-income countries, (4) Low- income countries for all hypothesis testing, as well as a separate country groups: (5) Oil-exporting countries only for the preparation of testing hypothesis 3. The classification of countries follows the World Bank's latest income classification standards for 2024. According to these standards, low-income economies are defined

[1] All countries and their classifications (4 countries groups) can be found in Appendix 1.

as those with a 2023 per capita gross national income (GNI) of $1,145 or less; lower-middle-income economies are those with a per capita GNI between $1,146 and $4,515; upper-middle-income economies are those with a per capita GNI between $4,516 and $14,005; and high-income economies are those with a per capita GNI exceeding $14,005 (The World Bank, 2024). The group of oil-exporting countries within the full sample consists of countries of OPEC numbers and OPEC+ numbers, extracted from the full sample, it includes Russian Federation, Nigeria, Kazakhstan, Mexico, Algeria, Gabon, Iran, Congo, Rep., Azerbaijan, Malaysia, Sudan (OPEC, 2024 and EIA, 2024). The research data exhibit panel data characteristics, and this paper simultaneously employs and compares four models: PVAR model, pooled model, fixed effects model, and random effects model. The article will consider specific factors to select the best model for validating different hypotheses, as detailed in the following sections.

At the beginning, the Panel Vector Autoregression (PVAR) model are considered to be used in the research for hypothesis 1 and 2. Because the Panel Vector Autoregression (PVAR) model is generally used in this field, for example there are precedents for using panel predictive regression model to analyze (Bannigidadmath et al., 2024), PVAR model including potential lag effects, it is more robust in handling the dynamic interactions among variables like changes in world uncertainty index affect economic growth through renewable energy consumption. That model requires a longer time series, and the use of data from 1997 to 2020 provides a sufficient timeframe for employing it. Moreover, in the choice of data, quarterly data is more appropriate than annual data for capturing fluctuations in world uncertainty.
Hypothesis 1 PVAR model specification:

$$G_{it} = \alpha_i + \beta_1 WUI_{it} + \sum_{j=1}^{p} \gamma_j G_{it-j} + \varepsilon_{it}$$

Hypothesis 2 PVAR model specification:

$$G_{it} = \partial_i + \mu_1 RECDif_{it} + \sum_{j=1}^{p} \delta_j G_{it-j} + \epsilon_{it}$$

Here, $G_{it}$ represents the economic growth rate of the $i$-th country (or region) at time $t$, $WUI_{it}$ represents the World Uncertainty Index of the $i$-th country (or region) at time $t$, $RECDif_{it}$ represents the first difference of renewable energy consumption of the $i$-th country (or region) at time $t$. $\alpha_i$ $and$ $\partial_i$ are the intercept specific to the country (or region), $\beta_1$ $and$ $\mu_1$ are the coefficient of $WUI_{it}$ and $RECDif_{it}$, $\gamma_j$ $and$ $\delta_j$ are the coefficient of economic growth at lag $j$, and $\varepsilon_{it}$ $and$ $\epsilon_{it}$ are the error terms.

However, the completeness and availability of data should also be considered. Since variables like REC cannot obtain quarterly data, and there are missing data issues for some countries. Using annual data does not present these problems. Thus, annual data is decided to be used to get a wider set of countries and using more variables for testing hypothesis 2 and 3.

However, for hypothesis 1, since quarterly data can better capture fluctuations for world uncertainty index (WUI), Panel Vector Autoregression( PVAR) model are more suitable to analyze dynamic relationships and potential lag effects, in that case, firstly, quarterly data and the (PVAR) model are decided to be used for checking the relationship between WUI and EG to exam the first research question and hypothesis 1 even though not all 88 countries have complete data. All the countries without missing data included in this test (Hypothesis 1) are highlighted in red in the Appendix 1. Subsequently, the thesis introduces the variable renewable energy consumption (REC) and utilizes annual data within a PVAR model to examine the relationship between renewable energy consumption and economic growth. This approach is taken to test Hypothesis 2 due to the unavailability of quarterly data for the renewable energy consumption variable. After that, the thesis tries to find whether changes in the level of world uncertainty index (WUI) affect economic growth through the renewable energy consumption (REC) (Hypothesis 3)? The panel regression model with annual data is used as the method and all variables appear in their original forms (Hypothesis 3 Model 1). Then, the dummy variables of world uncertainty index that will divided to High uncertainty and Low uncertainty will be introduced for the further test of hypothesis 3(Hypothesis 3 Model 2), and last but not least, an alternative test of including dummy variables in the model will be made to double check whether the findings of using model with dummies are reliable enough by distinguishing between high and low uncertainty situations and separately examining the relationship between renewable energy consumption(REC) and economic growth in each context(Hypothesis 3 model 3). Within the test for hypothesis 3, Firstly, it is essential to test for stationarity, heterogeneity, autocorrelation, and cross-sectional dependence in the data. Stationarity tests are used to examine the presence of unit root issues in the model. For panel data, stationarity tests are particularly important as they help determine whether the variables in the model exhibit consistent behavior patterns over time. Non-stationarity implies that the statistical properties of variables (e.g., their mean and variance) vary over time or across individuals. The presence of non-stationarity can lead to spurious regression results, where variables that have no causal relationship appear to have significant associations. Testing for stationarity helps ensure that the variables used in the panel data regression model are suitable for analysis, and that the results are reliable and meaningful. Testing for heterogeneity in panel data regression is also crucial, as it can determine whether systematic differences affect the relationship between the dependent variable (economic growth) and the independent variables. Significant heterogeneity might indicate that the drivers of economic growth vary across different countries, or that certain factors are more important in some countries than in others. To test for heterogeneity across countries/regions, this study will conduct the Breusch-Pagan/Cook-Weisberg (hettest) test. If the results of these tests indicate significant heterogeneity among these countries, a fixed effects model should be considered for the analysis.

Then, this thesis will test for autocorrelation and cross-sectional dependence by using the Breusch-Godfrey test and Pesaran's CD test. If the panel residuals are heteroscedastic and autocorrelated, a cluster or a heteroscedasticity-and-autocorrelation (HAC) robust estimator should be used to produce correct standard errors. Autocorrelation refers to the correlation of a variable's past values with its current values. In the context of this study, economic indicators such as GDP growth rate, renewable energy consumption, and global uncertainty may exhibit temporal dependence. For instance, GDP growth rates often follow cyclical patterns influenced by business cycles, policy changes, and external shocks. These cycles can result in serial correlation in the residuals of regression models. Secondly, cross-sectional dependence is also likely to be present. This can occur due to global economic events or spillover effects. For example, uncertainty arising from a global financial crisis or oil price shocks can simultaneously impact multiple countries, leading to synchronized economic fluctuations. Additionally, renewable energy policies and technological advancements in one country may have spillover effects, influencing renewable energy consumption and economic growth in neighbouring countries. The specific details of the data used in this study will be discussed in Section 3.4.

After that the decision of choosing from pooled, fixed effect, and random effect model is needed and will be done during the process by using Hausman test for choosing between Random effect and fixed effect model and using Breusch-Pagan LM test for choosing between Pooled and Random effect model.

The fixed effects model posits that the influence of independent variables remains consistent across all individuals or units in the sample, resulting in any changes in the dependent variable being solely ascribed to variations in the values of the independent variables. This model is commonly employed when researchers intend to draw causal inferences regarding the effects of specific treatments or interventions. Conversely, the random effects model assumes that the impact of independent variables varies randomly among individuals or units within the sample. Consequently, the variability in the dependent variable is influenced not only by differences in the independent variables but also by unobservable factors. Random effects models are often utilized when researchers aim to extend their findings to a broader population or when the data displays a hierarchical or clustered structure (Bannigidadmath et al., 2024). In deciding between fixed effects and random effects models, the Hausman test is commonly used as a method of comparison. This test assesses whether there is a statistically significant difference between the two models by comparing the estimated coefficients of the independent variables. If the estimated Hausman statistic is greater than the critical value, the null hypothesis is rejected, indicating that the two models yield different coefficients. In such cases, the random effects model is preferred. Alternatively, if the estimated Hausman statistic is less than the critical value, the null hypothesis is not rejected, and the fixed effects model is preferred. For validity, the Hausman test requires that the variance of the estimated coefficients in the random effects model be less than or equal to that in the fixed effects model. If this assumption is not met, the validity of the test may be questioned (Hausman, 2015; Bannigidadmath et al., 2024).

After Hausman test and Breusch-Pagan LM test, the fixed effect model should be used for testing hypothesis 3. Based on that, the lagged variable of G (G_lag1) will be added to get the effect of past economic performance on the current state of the economy. And add interaction term of WUI and REC to make this even for the FE model but it also can capture the main relationship this thesis focusing on. Compared to the commonly used VAR model in the literature, the fixed effect model has numerous advantages, such as increasing the total number of observations, reducing noise from individual time series regressions, and enhancing the power of the tests. This is particularly important especially when the availability of data is annual and limited (Bannigidadmath et al., 2024). This approach also has empirical support. Some recent papers in the same field using the Fixed effect model for example like Gara et al (2023) and using the Method of Moments Quantile Regression (MMQR) with fixed effects approach with annual data like Aslan et al (2024). In that case, using FE model with annual data is an acceptable choice for the research.

In that case, this thesis draws inspiration from the study by Le and Nguyen (2019) and extends the Cobb-Douglas production function as the baseline model:

$$Y = AK^{a1} L^{a2} RECDif^{a_3} WUI^{a_4} e^{\mu} [1]$$

where: $Y$ is real domestic output, $K$ is capital, $L$ is labour, $RECDif$ is the first difference of renewable energy consumption, $WUI$ is the World uncertainty index, $A$ is technological factor, and $e$ is error term.

Shahbaz et al. (2013)'s study suggests that in the extended Cobb-Douglas production function, technology can be endogenously influenced by trade openness and financial development. Numerous studies highlight the significance of financial development in determining output, primarily through its positive effects on the accumulation of physical and human capital. According to Le and Nguyen (2019)'s research, in an open economy, advanced levels of financial development foster a more conducive environment for foreign direct investment, leading to enhanced technology transfer and improved management skills.

Furthermore, the growth impacts of trade openness have been extensively examined within the framework of endogenous growth models, as demonstrated by Rivera-Batiz and Romer (1991a, 1991b). These models assert that trade openness generally stimulates economic growth by boosting domestic productivity through advancements in innovation and technology development (Shahbaz et al., 2013; Le, 2016; Le and Tran-Nam, 2018). Consequently, the significance of trade openness and financial development is integrated into the technological progress component of the extended Cobb-Douglas production function, as outlined below:

$$A = \delta TO_t^{\emptyset} FD_t^{\theta} \quad [2]$$

Equation [2] is put into equation [1] as follows:

$$Y = \delta TO_t^{\emptyset} FD_t^{\theta} K^{a1} L^{a2} REC^{a_3} GPR^{a_4} \ [3]$$

**Hypothesis 3 Model 1 specification:**

$$G_{it} = \alpha + \beta_1 \text{WUI}_{it} + \beta_2 RECDif_{it} + \beta_3 (\text{WUI}_{it} \times RECDif_{it}) + \beta_4 X_{it} + f_i + \lambda_t + u_{it} \ [4]$$

Except for the main variables like world uncertainty index and renewable energy consumption difference, and control variables like gross capital formation and trade openness that already explained above, the rest of control variables are based on analyzing the previous literature such as Barro (2003), Batten & Vo (2009), Teixeira & Queiros (2016), Soybilgen et al. (2019), Saukani et al. (2002). The specific details and sources of the data are showing below in Table 1.

Table 1: Variables Summary

| Symbol | Variables | Sources |
|---|---|---|
| WUI | World Uncertainty Index | (World Uncertainty Index,2024) |

| | | |
|---|---|---|
| $REC$ | REC: Total, % of primary energy supply | WDI |
| $RECDif$ | The first difference of Renewable Energy Consumption, which is the difference between the current period's REC value and the previous period's REC value. | |
| $G$ | GDP growth(%annual); Quarterly data for GDP growth rate | WDI; OECD |
| $G\_lag_1$ | Lag of real GDP growth (Growth (-1)) | |
| $n$ | Population growth rate | WDI |
| $Trade$ | Trade (% of GDP) | WDI |
| $Gov$ | General government final consumption expenditure (% of GDP) | WDI |
| $Cap$ | Gross capital formation (% of GDP) | WDI |

- $\alpha$: Intercept term, representing the average economic growth across all countries (or regions) when all independent variables are zero.
- $\beta 1$: Coefficient of the World Uncertainty Index (*WUIit*), representing the effect of global uncertainty on economic growth.
- $\beta 2$: Coefficient of the Renewable Energy Consumption Difference (*RECDifit*), representing the effect of the difference in renewable energy consumption on economic growth.

- $\beta 3$: Coefficient of the interaction term between *WUIit* and *RECDifit*, representing the combined effect of global uncertainty and the difference in renewable energy consumption on economic growth.

  $\beta 4$: Coefficient of other control variables represented by *Xit*, such as population growth rate, trade (% of GDP), general government final consumption expenditure (% of GDP), gross capital formation (% of GDP) on economic growth and Lag of real GDP growth.
- *fi*: Fixed effects specific to each country (or region), capturing unobserved heterogeneity that is constant over time.
- $\lambda t$: Time fixed effects capturing time-specific factors affecting economic growth across all countries (or regions).
- *uit*: Error term capturing unobserved factors affecting economic growth not accounted for by the model.

Based on data from the World Bank's World Development Indicators (WDI), OECD data and the World Uncertainty Index website, this thesis conducts an empirical analysis of a panel dataset covering 88 countries from 1997 to 2020. The sample is divided into three subsamples based on income levels and includes a group of oil-exporting countries within the full sample. There are 26 low-income countries, 44 middle-income countries, 34 high-income countries, and 11 oil-exporting countries. Table 2 presents the data description for the full samples and for three income level countries plus one sub-samples of oil export countries. The correlation matrix for the full sample is showing in Table 3.

Table 2: Statistical descriptions for the full 88 samples, three income level countries (High-income countries, Lower and Upper-middle income countries, Low-income countries, and oil export countries.

| **Full 88 countries** | **Obs** | **Mean** | **Std. dev.** | **Min** | **Max** |
|---|---|---|---|---|---|
| G | 2200 | 3.343284 | 3.979012 | -21.3999 | 34.5 |
| n | 2200 | 1.313362 | 1.19722 | -2.879866 | 16.6255 |
| TRADE | 2200 | 79.08702 | 55.03142 | 9.955145 | 442.62 |
| GOV | 2200 | 15.53012 | 5.046938 | 2.057589 | 36.14305 |
| CAP | 2200 | 23.66806 | 6.853181 | -2.424358 | 76.78231 |
| REC | 2200 | 31.02753 | 28.25354 | 0.05 | 98.34 |
| WUI | 2200 | 0.183726 | 0.1550991 | 0 | 1.34288 |
| G_lag1 | 2112 | 3.638816 | 3.676951 | -20.49107 | 34.5 |
| RECDif | 2112 | -0.0309943 | 1.641075 | -13.13 | 11.5 |
| | | | | | |
| **High income countries** | **Obs** | **Mean** | **Std. dev.** | **Min** | **Max** |
| G | 850 | 2.345139 | 3.252003 | -14.11538 | 24.47525 |
| n | 850 | 0.5205368 | 0.7575282 | -2.170699 | 5.321517 |
| TRADE | 850 | 99.22074 | 74.42211 | 18.12563 | 442.62 |
| GOV | 850 | 18.62197 | 4.108132 | 8.043869 | 27.935 |
| CAP | 850 | 23.72136 | 4.3109 | 1.157311 | 54.7747 |
| REC | 850 | 14.89484 | 13.36225 | 0.05 | 61.29 |
| WUI | 850 | 0.1815249 | 0.1382334 | 0 | 1.179749 |
| G_lag1 | 816 | 2.615708 | 2.952955 | -14.11538 | 24.47525 |
| RECDif | 816 | 0.385 | 1.143349 | -6.2 | 7.01 |
| | | | | | |
| **Middle income countries** | **Obs** | **Mean** | **Std. dev.** | **Min** | **Max** |

| | | | | | |
|---|---|---|---|---|---|
| G | 1100 | 3.819796 | 4.109883 | -21.3999 | 34.5 |
| n | 1100 | 1.547602 | 0.9529738 | -2.879866 | 9.97197 |
| TRADE | 1100 | 70.52781 | 33.39372 | 15.63559 | 220.4068 |
| GOV | 1100 | 13.75394 | 4.677198 | 3.460336 | 36.14305 |
| CAP | 1100 | 24.71198 | 7.961145 | 8.098177 | 76.78231 |
| REC | 1100 | 31.54524 | 24.69159 | 0.06 | 94.27 |
| WUI | 1100 | 0.1901586 | 0.1694967 | 0 | 1.34288 |
| G_lag1 | 1056 | 4.153079 | 3.716974 | -15.13647 | 34.5 |
| RECDif | 1056 | -0.2632481 | 1.794878 | -12.1 | 11.5 |
| | | | | | |
| **Low-income countries** | **Obs** | **Mean** | **Std. dev.** | **Min** | **Max** |
| G | 250 | 4.64033 | 4.808191 | -20.49107 | 26.52413 |
| n | 250 | 2.978313 | 1.233707 | 0.5355707 | 16.6255 |
| TRADE | 250 | 48.2929 | 16.70752 | 9.955145 | 90.74761 |
| GOV | 250 | 12.83303 | 4.120283 | 2.057589 | 24.38959 |
| CAP | 250 | 18.8936 | 6.63031 | -2.424358 | 42.07522 |
| REC | 250 | 83.60076 | 9.238627 | 58.85 | 98.34 |
| WUI | 250 | 0.1629063 | 0.140911 | 0 | 0.9078333 |
| G_lag1 | 240 | 4.85462 | 4.740081 | -20.49107 | 26.52414 |
| RECDif | 240 | -0.4234583 | 2.031009 | -13.13 | 6.46 |
| | | | | | |
| **Oil export countries** | **Obs** | **Mean** | **Std. dev.** | **Min** | **Max** |
| G | 175 | 2.733703 | 3.323068 | -8.651587 | 13.5 |
| n | 175 | 0.9348947 | 0.7075306 | -1.728416 | 1.999946 |
| TRADE | 175 | 59.0475 | 18.09474 | 15.63559 | 105.6997 |

| | | | | | |
|---|---|---|---|---|---|
| GOV | 175 | 16.73753 | 4.357245 | 7.665138 | 26.13406 |
| CAP | 175 | 24.60259 | 6.970598 | 14.62559 | 50.78069 |
| REC | 175 | 20.17246 | 21.4172 | 0.06 | 61.29 |
| WUI | 175 | 0.2105071 | 0.1649599 | 0 | 1.0902 |
| G_lag1 | 168 | 3.017241 | 3.044487 | -7.799994 | 13.5 |
| RECDif | 168 | 0.0597619 | 0.7388792 | -3.24 | 2.47 |

Table 3: Correlation matrix.

| Correlations | G | WUI | RECDif | G_lag1 | n | TRADE | GOV | CAP |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| G | 1 | | | | | | | |
| | | | | | | | | |
| WUI | -0.1988* | 1 | | | | | | |
| | 0 | | | | | | | |
| RECDif | -0.2152* | 0.0878* | 1 | | | | | |
| | 0 | 0.0001 | | | | | | |
| G_lag1 | 0.3982* | -0.1361* | -0.1228* | 1 | | | | |
| | 0 | 0 | 0 | | | | | |
| n | 0.2082* | -0.0469* | -0.1785* | 0.2048* | 1 | | | |
| | 0 | 0.0279 | 0 | 0 | | | | |
| TRADE | 0.025 | -0.0716* | 0.0602* | 0.0238 | -0.1515* | 1 | | |
| | 0.2407 | 0.0008 | 0.0057 | 0.2745 | 0 | | | |
| GOV | -0.2706* | 0.0680* | 0.2012* | -0.2628* | -0.3669* | 0.0212 | 1 | |
| | 0 | 0.0014 | 0 | 0 | 0 | 0.3197 | | |
| CAP | 0.1931* | -0.1101* | -0.0566* | 0.2172* | -0.0425* | 0.1604* | 0.0123 | 1 |
| | 0 | 0 | 0.0093 | 0 | 0.0462 | 0 | 0.5635 | |

When analyzing the impact of renewable energy consumption on economic growth (Hypotheses 2 and 3), this article utilizes the first difference of Renewable Energy Consumption ($RECDif$), which is the difference between the current period's REC value and the previous period's REC value, instead of directly using the level of REC. This choice is motivated by several reasons:1) There may be endogeneity issues when studying the relationship between REC and economic growth. For instance, when REC is correlated with the error term in the regression model, this correlation can distort the estimated coefficients, leading to biased and inconsistent results. Omitted variable bias may also exist, where unobserved factors simultaneously influence both the independent variable and the dependent variable. For example, factors such as government policies, technological advancements, or economic conditions may simultaneously affect renewable energy consumption and economic growth. Thirdly, endogeneity may also occur due to simultaneity bias, where the relationship between REC and economic growth is bidirectional. Failing to account for this bidirectional relationship can result in biased estimates. However, using the first difference of REC helps mitigate endogeneity issues, as it captures changes in renewable energy consumption over time. By differencing the data, it eliminates time-invariant country-specific factors that may be correlated with both REC and economic growth but remain constant over time, such as institutional quality or cultural factors. 2) By focusing on changes in renewable energy generation rather than its absolute level, we can better capture the dynamic adjustment process within countries' energy systems and highlight potential threshold effects in the relationship between renewable energy consumption and economic growth. Some countries may maintain consistently high levels of renewable energy consumption due to long-standing policies or abundant renewable resources, while others may experience sudden increases in renewable energy consumption due to new policy measures, technological advancements, or changes in energy prices. For countries with already high levels of renewable energy generation, further increases may lead to diminishing marginal returns in stimulating economic growth. In contrast, countries experiencing significant increases in renewable energy generation may undergo transformative changes in their energy systems, resulting in more pronounced impacts on economic growth. 3) By focusing on changes in renewable energy consumption (REC), we can gain a better understanding of the dynamic relationship between policy interventions and economic outcomes.

**Hypothesis 3 Model 2 specification (Dummy variables):**

The thesis tries to find whether changes in the level of world uncertainty index (WUI) affect economic growth through the renewable energy consumption (REC) by using dummy variables in this section.

This paper will classify a country *j* as facing a higher-than-average degree of uncertainty when its annual uncertainty is above the median value obtained from the distribution of all countries. Hence, the high uncertainty dummy is defined as:

$$HU_{j.t} = \begin{cases} 1, if(\sigma)_{j,t} > \sigma^{med} \\ 0, \quad otherwise \end{cases}$$

$$G_{it} = \alpha + \beta_1 \text{WUI}_{it} + \beta_2 RECDif_{it} + \beta_3 (\text{HU}_{it} \times RECDif_{it}) + \beta_4 X_{it} + f_i + \lambda_t + u_{it}$$

On the contrary the Low uncertainty dummy is defined as:

$$LU_{j.t} = \begin{cases} 1, if(\sigma)_{j,t} < \sigma^{med} \\ 0, \quad otherwise \end{cases}$$

$$G_{it} = \alpha + \beta_1 \text{WUI}_{it} + \beta_2 RECDif_{it} + \beta_3 (\text{LU}_{it} \times RECDif_{it}) + \beta_4 X_{it} + f_i + \lambda_t + u_{it}$$

**Hypothesis 3 Model 3 specification:**

For High/ Low uncertainty situation:

$$G_{it} = \alpha + \beta_1 RECDif_{it} + \beta_2 X_{it} + f_i + \lambda_t + u_{it}$$

Hypothesis 3 Model 3 utilizes the same uncertainty classification method as Hypothesis 3 Model 2. Specifically, it categorizes annual uncertainty as a high uncertainty situation when it exceeds the mean derived from the distribution across all countries, and as a low uncertainty situation when it falls below this mean. The relationship between renewable energy consumption and GDP growth rate is then analysed separately under these two scenarios.

# 3. Empirical Results

## 3.1World uncertainty index and Economic Growth (test hypothesis 1) (Method: PVAR model, Quarterly data)

Table 4:

```
.
. esttab Model1 Model2 Model3
```

| | (1) G | (2) G | (3) G |
|---|---|---|---|
| **G** | | | |
| L.G | -0.120** | -0.182** | -0.00619 |
| | (-2.66) | (-3.23) | (-0.07) |
| L2.G | 0.0301 | -0.0305 | 0.139* |
| | (0.66) | (-0.47) | (2.18) |
| L.WUI | -2.530* | -3.120* | -2.098 |
| | (-2.54) | (-2.26) | (-1.46) |
| L2.WUI | -2.064* | -2.572 | -1.764 |
| | (-2.04) | (-1.83) | (-1.29) |
| **WUI** | | | |
| L.G | -0.0142*** | -0.0221*** | -0.00393 |
| | (-5.15) | (-5.46) | (-1.02) |
| L2.G | -0.0162*** | -0.0243*** | -0.00725 |
| | (-5.21) | (-5.64) | (-1.41) |
| L.WUI | 0.254*** | 0.101 | 0.437*** |
| | (3.55) | (1.04) | (3.50) |
| L2.WUI | -0.0361 | -0.199* | 0.192* |
| | (-0.64) | (-2.52) | (1.99) |
| N | 3534 | 2790 | 744 |

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

The empirical results derived from the PVAR model are presented in Table 4. The table contains three sets of results: (1) All 88 countries, (2) High-income countries, and (3) Middle-income countries. Since there are some missing data for Low-income countries, the results will not be present here.

First of all, for the full sample of 88 countries ((1) in Table 4), the results are as follows:

1) Economic Growth Equation: The coefficient for the first lag of economic growth (L.G) is negative (-0.120) and statistically significant at the 1% level ($p < 0.01$). This

indicates a negative relationship between lagged economic growth and current economic growth, suggesting that past growth downturns continue to affect current growth negatively. The second lag of economic growth (L2.G) is not significant, implying that more distant past growth does not have a significant impact on current growth. The first lag of the World Uncertainty Index (L.WUI) has a coefficient of -2.530, significant at the 5% level ($p < 0.05$), indicating that higher uncertainty in the previous period significantly reduces current economic growth. The second lag of the World Uncertainty Index (L2.WUI) also shows a negative coefficient of -2.064, significant at the 5% level, reinforcing the negative impact of past uncertainty on current growth, and recent uncertainty has a greater impact on economic growth than uncertainty occurring in the more distant past.

2) Uncertainty Equation: The first lag of economic growth (L.G) has a coefficient of -0.0142, highly significant at 0.1% level ($p < 0.001$), suggesting that past economic growth reduces current uncertainty. The second lag of economic growth (L2.G) also shows a negative coefficient of -0.0162 and statistically significant at the 0.1% level ($p < 0.001$)， also suggesting that past economic growth reduces current uncertainty. Comparing these findings with findings above reveals that the impact of uncertainty on economic growth is significantly greater than the impact of economic growth on uncertainty. The first lag of the World Uncertainty Index (L.WUI) has a positive coefficient of 0.254, significant at the 0.1% level, indicating that past uncertainty increases current uncertainty. The second lag of the World Uncertainty Index (L2.WUI) is insignificant.

Table 5:

```
. pvargranger

  panel VAR-Granger causality Wald test
    Ho: Excluded variable does not Granger-cause Equation variable
    Ha: Excluded variable Granger-causes Equation variable
```

| Equation \ Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|
| **G** | | | |
| WUI | **6.709** | **2** | **0.035** |
| ALL | **6.709** | **2** | **0.035** |
| **WUI** | | | |
| G | **30.591** | **2** | **0.000** |
| ALL | **30.591** | **2** | **0.000** |

The results of the Granger causality test in Table 5 indicate a bidirectional causal relationship between the World Uncertainty Index (WUI) and GDP growth. Specifically: The World Uncertainty Index (WUI) Granger-causes GDP growth, as indicated by the p-value of 0.035, which is statistically significant. GDP growth Granger-causes the World Uncertainty Index (WUI), with a highly significant p-value of 0.000. These findings suggest a dynamic interdependence between economic growth and world uncertainty. Increases in uncertainty can predict changes in economic growth, and changes in economic growth can predict variations in uncertainty. Hypothesis 1 states that economic growth decreases with increasing uncertainty. The Granger causality test results support the notion that uncertainty influences economic growth to a certain extent. However, the bidirectional nature of the relationship indicates that economic growth also affects uncertainty.

Table 6:

```
. pvarstable,graph

   Eigenvalue stability condition
```

| Eigenvalue Real | Eigenvalue Imaginary | Modulus |
|---|---|---|
| .5833768 | 0 | .5833768 |
| -.0478876 | .4066587 | .4094686 |
| -.0478876 | -.4066587 | .4094686 |
| -.3531048 | 0 | .3531048 |

```
   All the eigenvalues lie inside the unit circle.
   pVAR satisfies stability condition.
```

This PVAR model satisfies the stability condition, as shows in table 6, it indicates that the model is stable, and the variables will not exhibit explosive behaviour over time. This means that the system of equations in the PVAR model has eigenvalues with moduli less than one, ensuring that shocks to the system will dissipate and the variables will return to their equilibrium levels, making the model's predictions reliable and meaningful.

Secondly, for high-income countries ((2) in Table 4), the tests results are stronger compared to it for the full sample set:

1)Economic Growth Equation: The first lag of economic growth (L.G) has a negative coefficient of -0.182, statistically significant at the 1% level, indicating a stronger negative impact of past growth on current growth compared to the full sample. The second lag of economic growth (L2.G) is not significant. The first lag of the World Uncertainty Index (L.WUI) has a negative coefficient of -3.120, significant at the 5% level, indicating a pronounced negative effect of past uncertainty on current growth which is a weaker negative impact of past growth on current growth compared to the full sample. This may suggest that high-income countries exhibit greater economic stability and resilience. These economies may have established mechanisms to mitigate the adverse effects of past economic downturns, enabling them to recover more rapidly and maintain a more stable growth trajectory. High-income countries likely benefit from more robust institutions, diversified economies, and better crisis management strategies, which help to alleviate the impact of past negative growth on current performance. The second lag of the World Uncertainty Index (L2.WUI) is insignificant.

2)Uncertainty Equation: the coefficient of first lag of economic growth (L.G) is negative (-0.022) and statistically significant at the 0.1% level. The coefficient of second lag of economic growth (L2.G) is also negative and statistically significant at the 0.1% level. It can be observed that, compared to the full countries group, economic growth in high-income countries is more significantly affected by uncertainty. The first lag of the World Uncertainty Index (L.WUI) is insignificant. The second lag of the World Uncertainty Index (L2.WUI) has a negative coefficient of -0.199, significant at the 5% level.

Table 7:

```
. pvargranger

  panel VAR-Granger causality Wald test
    Ho: Excluded variable does not Granger-cause Equation variable
    Ha: Excluded variable Granger-causes Equation variable
```

| Equation \ Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|
| **G** | | | |
| WUI | **5.717** | **2** | **0.057** |
| ALL | **5.717** | **2** | **0.057** |
| **WUI** | | | |
| G | **34.866** | **2** | **0.000** |
| ALL | **34.866** | **2** | **0.000** |

The results show in the table 7 of the Granger causality test indicate a same bidirectional causal relationship between the World Uncertainty Index (WUI) and GDP growth for high-income countries. Compared to the full sample set, for high income countries, increases in uncertainty and changes in economic growth exhibit stronger predictive power for economic growth and changes in uncertainty, respectively.

Table 8:

```
. pvarstable

   Eigenvalue stability condition
```

| Eigenvalue Real | Eigenvalue Imaginary | Modulus |
|---|---|---|
| -.1253361 | -.5757876 | .5892712 |
| -.1253361 | .5757876 | .5892712 |
| .4965527 | 0 | .4965527 |
| -.3272924 | 0 | .3272924 |

```
   All the eigenvalues lie inside the unit circle.
   pVAR satisfies stability condition.
```

As shown in Table 8, the PVAR model for high-income countries satisfies the stability condition, indicating that the model's predictions are reliable and meaningful.

Thirdly, for middle-income countries ((3) in Table 4), most of coefficients are insignificant except the second lag of the GDP growth has a coefficient of 0.139 significant at the 0.1% level, indicating that for middle-income countries, past economic growth is beneficial for today's economic growth, the level is higher than it for full countries set and for high income countries. And the first and second lag of World Uncertainty Index are both positive and statistically significant, means past uncertainty has the significantly increases current uncertainty.

Table: 9

```
. pvargranger

  panel VAR-Granger causality Wald test
    Ho: Excluded variable does not Granger-cause Equation variable
    Ha: Excluded variable Granger-causes Equation variable
```

| Equation \ Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|
| **G** | | | |
| WUI | **2.269** | **2** | **0.322** |
| ALL | **2.269** | **2** | **0.322** |
| **WUI** | | | |
| G | **2.001** | **2** | **0.368** |
| ALL | **2.001** | **2** | **0.368** |

The results of the Granger causality test show in the table 9, for middle-income countries indicate no significant Granger-causal relationship between the World Uncertainty Index (WUI) and GDP growth rate in either direction. These findings suggest that changes in the World Uncertainty Index do not predict changes in GDP growth, nor do changes in GDP growth predict changes in the World Uncertainty Index for the middle-income countries in the sample. This lack of significant causal relationships implies that economic growth and global uncertainty may be influenced by other factors not captured in this model even if this model satisfy the stability condition (Table 10), there are some more important factors lead the changes of middle-income countries.

Table 10:

```
. pvarstable

  Eigenvalue stability condition
```

| Eigenvalue Real | Eigenvalue Imaginary | Modulus |
|---|---|---|
| .7789519 | 0 | .7789519 |
| -.415671 | 0 | .415671 |
| .2442046 | 0 | .2442046 |
| -.1770441 | 0 | .1770441 |

```
  All the eigenvalues lie inside the unit circle.
  pVAR satisfies stability condition.
```

In conclusion, the results of this study largely support Hypothesis 1, which posits that economic growth decreases as global uncertainty increases. Specifically, for the full sample of 88 countries, increased uncertainty in previous periods significantly reduces current economic growth, confirming the hypothesis that rising global uncertainty adversely affects economic performance. Additionally, past economic growth tends to reduce current uncertainty, suggesting that stronger economic performance in the past contributes to greater economic stability. Notably, the impact of uncertainty on economic growth is significantly greater than the impact of economic growth on uncertainty, indicating a dynamic interdependence between these variables. This means that changes in uncertainty can predict fluctuations in economic growth, and vice versa.

In high-income countries, the results show a pronounced negative effect of past uncertainty on current growth, highlighting that these economies are more sensitive to global uncertainty compared to the full sample. Furthermore, economic growth in high-income countries is more significantly affected by uncertainty. And there is a same bidirectional causal relationship between the World Uncertainty Index (WUI) and GDP growth for high-income countries.

For middle-income countries, the study finds that the impact of past uncertainty on current growth is not significant. This implies that middle-income countries may respond differently to global uncertainty compared to high-income countries, potentially due to varying structural characteristics or coping mechanisms. Additionally, there is no significant Granger-causal relationship between the World Uncertainty Index (WUI) and GDP growth in either direction for middle-income countries. This absence of a causal relationship suggests that changes in global uncertainty do not predict changes in GDP growth and vice versa, reflecting potentially distinct structural or adaptive responses in these economies.

# 3.2 Renewable Energy Consumption and Economic Growth (test hypothesis 2) (Method: PVAR model, Annual data)

Table 11：

```
. esttab Model1 Model2 Model3 Model4
```

| | (1) G | (2) G | (3) G | (4) G |
|---|---|---|---|---|
| **G** | | | | |
| L.G | 0.612*** | 0.637*** | 0.704*** | 0.302* |
| | (10.00) | (5.92) | (8.41) | (2.25) |
| L2.G | 0.307*** | 0.279*** | 0.334*** | 0.223 |
| | (5.57) | (3.94) | (4.43) | (1.44) |
| L.RECDif | -0.0821 | 0.292 | -0.143 | -0.345* |
| | (-1.20) | (1.77) | (-1.75) | (-2.02) |
| L2.RECDif | 0.0151 | 0.193 | -0.0714 | 0.0811 |
| | (0.22) | (1.39) | (-0.87) | (0.55) |
| **RECDif** | | | | |
| L.G | -0.0795*** | -0.107*** | -0.101*** | 0.00593 |
| | (-4.61) | (-4.91) | (-3.87) | (0.14) |
| L2.G | -0.0389** | -0.0609** | -0.0302 | -0.0340 |
| | (-2.60) | (-3.27) | (-1.36) | (-0.97) |
| L.RECDif | -0.0302 | -0.273*** | -0.0152 | 0.171 |
| | (-0.72) | (-4.09) | (-0.27) | (1.54) |
| L2.RECDif | -0.0611 | -0.179** | -0.0239 | -0.105 |
| | (-1.56) | (-2.71) | (-0.44) | (-1.41) |
| N | 1848 | 714 | 924 | 210 |

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

The empirical results derived from the PVAR model for the relationship between renewable energy consumption difference (RECDif) and economic growth (G) are presented in Table 5. The table contains four sets of results: (1) All 88 countries, (2) High-income countries, (3) Middle-income countries, and (4) Low-income countries.

The hypothesis 2 posited in this study is that economic growth increases with higher renewable energy consumption. The data from the PVAR model provide varying degrees of support for this hypothesis, particularly highlighting distinctions across different income levels.

(1) For all 88 Countries group ((1) in Table 11):
For the overall sample of 88 countries, the data do not show a significant direct positive relationship between renewable energy consumption differences and GDP growth. The coefficients for L.RECDif (-0.0821) and L2.RECDif (0.0151) are not statistically significant. However, there are the significant negative impact of GDP growth on renewable energy consumption differences at 0.1% and 1% level (L.G: -0.0795, L2.G: -0.0389) indicates that as economic growth, the renewable energy consumption difference tends to decrease. This may suggest that existing economic structures favor non-renewable energy sources or as the economy grows, fluctuations in renewable energy consumption (whether increasing or decreasing) are diminishing, and the rate of growth in renewable energy consumption is slowing relative to economic growth.

Table 12:

```
. pvargranger

  panel VAR-Granger causality Wald test
    Ho: Excluded variable does not Granger-cause Equation variable
    Ha: Excluded variable Granger-causes Equation variable
```

| Equation \ Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|
| **G** | | | |
| RECDif | 1.845 | 2 | 0.398 |
| ALL | 1.845 | 2 | 0.398 |
| **RECDif** | | | |
| G | 23.930 | 2 | 0.000 |
| ALL | 23.930 | 2 | 0.000 |

.

For Economic Growth Equation, the p-value for both tests is 0.398, which is greater than the conventional significance level of 0.05. Therefore, the null hypothesis cannot be rejected, indicating that renewable energy consumption differences do not Granger-cause GDP growth. For RECDif Equation The p-value for both tests is 0.000, which is less than the conventional significance level of 0.05. Therefore, null hypothesis can be rejected, indicating that GDP growth does Granger-cause renewable energy consumption differences. The results of the Granger causality test indicate that while renewable energy consumption differences do not predict GDP growth, GDP growth does predict changes in renewable energy consumption differences. This suggests a unidirectional causal relationship where economic growth drives changes in renewable energy consumption patterns rather than the other way around.

Table 13:

```
. pvarstable

   Eigenvalue stability condition
```

| Eigenvalue Real | Eigenvalue Imaginary | Modulus |
|---|---|---|
| .9449224 | 0 | .9449224 |
| -.3243892 | 0 | .3243892 |
| -.0193591 | -.2427695 | .2435401 |
| -.0193591 | .2427695 | .2435401 |

```
   All the eigenvalues lie inside the unit circle.
   pVAR satisfies stability condition.
```

This PVAR model satisfies the stability condition, as shows in table 13, it indicates that the model is stable, and the variables will not exhibit explosive behaviour over time. This means that the system of equations in the PVAR model has eigenvalues with moduli less than one, ensuring that shocks to the system will dissipate and the variables will return to their equilibrium levels, making the model's predictions reliable and meaningful.

(2) High-Income Countries ((2) in Table 11):

In high-income countries, the relationship between renewable energy consumption differences and economic growth is more complex. The first lag of renewable energy consumption difference (L.RECDif: 0.292) positively affects GDP growth but is not statistically significant at conventional levels. The coefficients for subsequent periods (L2. RECDif: 0.193) also remain insignificant. However, GDP growth has a negative impact on renewable energy consumption changes (L.G: -0.107, L2.G: -0.0609) at 0.1% and 1% significant level, suggesting that in high-income countries, economic expansion may initially rely on non-renewable energy sources or that improvements in energy efficiency might reduce the growth in renewable energy consumption.

The positive autocorrelation of GDP growth (L.G: 0.637, L2.G: 0.279) at 0.1% significant level highlights strong economic momentum, which might support sustained investments in renewable energy infrastructure once initial growth phases stabilize. High-income countries often have the resources and technology to transition towards renewable energy in the long term, even if short-term dynamics show a negative relationship.

Table 14:

```
. pvargranger

  panel VAR-Granger causality Wald test
    Ho: Excluded variable does not Granger-cause Equation variable
    Ha: Excluded variable Granger-causes Equation variable
```

| Equation \ Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|
| **G** | | | |
| RECDif | 3.499 | 2 | 0.174 |
| ALL | 3.499 | 2 | 0.174 |
| **RECDif** | | | |
| G | 26.481 | 2 | 0.000 |
| ALL | 26.481 | 2 | 0.000 |

For Economic Growth Equation, the p-value for both tests is 0.174, which is greater than the conventional significance level of 0.05. Therefore, the null hypothesis cannot be rejected, indicating that renewable energy consumption differences do not Granger-cause GDP growth. For RECDif Equation The p-value for both tests is 0.000, which is less than the conventional significance level of 0.05. Therefore, null hypothesis can be rejected, indicating that GDP growth does Granger-cause renewable energy consumption differences. The results of the Granger causality for high-income countries test show a clear unidirectional causal relationship where GDP growth predicts changes in renewable energy consumption differences, but not vice versa. This finding suggests that economic growth drives changes in renewable energy consumption, implying that periods of economic expansion are associated with significant adjustments in renewable energy consumption patterns.

Table 15:

```
. pvarstable

   Eigenvalue stability condition
```

| Eigenvalue Real | Eigenvalue Imaginary | Modulus |
|---|---|---|
| .8856974 | 0 | .8856974 |
| -.1193131 | -.3709173 | .3896348 |
| -.1193131 | .3709173 | .3896348 |
| -.2831158 | 0 | .2831158 |

```
   All the eigenvalues lie inside the unit circle.
   pVAR satisfies stability condition.
```

This PVAR model satisfies the stability condition for high income countries, as shows in table 15, it indicates that the model is stable, and model's predictions are reliable and meaningful.

(3) Middle-Income Countries ((3) in Table 11):

For middle-income countries, the analysis shows strong positive autocorrelation in GDP growth (L.G: 0.704, L2. G: 0.334) at 0.1% significant level, but renewable energy consumption differences do not significantly impact GDP growth rate (L.RECDif: -0.143, L2.RECDif: -0.0714). The coefficient of first lag of GDP growth rate is negative (-0.101) and statistically significant at the 0.1% level.This indicates that middle-income countries might be in a transitional phase where economic growth does not yet heavily depend on renewable energy consumption. The negative impact of GDP growth on renewable energy consumption differences further underscores that current economic growth might still be tied to conventional energy sources.

Table 16:

```
. pvargranger

  panel VAR-Granger causality Wald test
    Ho: Excluded variable does not Granger-cause Equation variable
    Ha: Excluded variable Granger-causes Equation variable
```

| Equation \ Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|
| **G** | | | |
| RECDif | 3.404 | 2 | 0.182 |
| ALL | 3.404 | 2 | 0.182 |
| **RECDif** | | | |
| G | 15.281 | 2 | 0.000 |
| ALL | 15.281 | 2 | 0.000 |

The results of the Granger causality for middle-income countries test show a same result as above tests of high-income countries which is a clear unidirectional causal relationship where GDP growth predicts changes in renewable energy consumption differences, but not vice versa.

Table 17:

```
. pvarstable,graph

   Eigenvalue stability condition
```

| Eigenvalue Real | Eigenvalue Imaginary | Modulus |
|---|---|---|
| 1.048186 | 0 | 1.048186 |
| -.3241877 | 0 | .3241877 |
| -.0174277 | .1720047 | .1728854 |
| -.0174277 | -.1720047 | .1728854 |

```
   At least one eigenvalue lie outside the unit circle.
   pVAR does not satisfy stability condition.
```

However, PVAR does not satisfy stability condition. Although the panel vector autoregression (PVAR) model may reveal some significant coefficients when analyzing the economic dynamics of middle-income countries, indicating potential short-term dynamic relationships between variables, it is important to note that if the PVAR model does not satisfy the stability condition, its long-term predictive reliability is compromised. The stability condition is fundamental to ensuring that the model can capture the long-term equilibrium relationships between variables. If a model fails to meet these conditions, the significant coefficients it reveals may only reflect short-term fluctuations rather than genuine long-term relationships between economic variables. This can lead to misunderstandings of economic trends and policy effects. For middle-income countries, this distinction between short-term and long-term analysis is particularly crucial. These countries may be at critical stages of economic transformation and require accurate long-term forecasts to guide policy-making and economic planning. If the stability condition of the model is not satisfied, predictions based on this model may not accurately reflect future economic directions, thereby affecting the effectiveness and sustainability of policies. Therefore, when analyzing the PVAR model for middle-income countries, it is essential to adopt a nuanced approach to interpreting the significant coefficients. While these coefficients should not be dismissed for their potential value in explaining short-term economic phenomena, it is equally important to recognize that without proper testing and adjustment for model stability, these findings may not provide a reliable basis for long-term economic analysis.

(4) Low-Income Countries ((4) in Table 11):

For low-income countries, the coefficient of first lag of the renewable energy consumption differences (L.RECDif ) and economic growth rate is negative(-0.345) and statistically significant at 5% level. And the coefficient of first lag of the economic growth rate and GDP growth rate for now is positive (0.302) and statistically significant at 5% level. However, for the rest of coefficient, the data show insignificant relationships, for instant, GDP growth rate does not significantly impact renewable energy consumption differences. This suggests that low-income countries face structural and financial barriers to integrating renewable energy into their economies. Economic growth in these regions may depend more on traditional energy sources due to a lack of infrastructure and investment in renewable energy.

Table 18:

```
. pvargranger

  panel VAR-Granger causality Wald test
    Ho: Excluded variable does not Granger-cause Equation variable
    Ha: Excluded variable Granger-causes Equation variable
```

| Equation \ Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|
| **G** | | | |
| RECDif | 5.242 | 2 | 0.073 |
| ALL | 5.242 | 2 | 0.073 |
| **RECDif** | | | |
| G | 1.278 | 2 | 0.528 |
| ALL | 1.278 | 2 | 0.528 |

.

For low-income countries, according to Table 18, The Granger causality test results reveal an absence of a significant Granger-causal link between GDP growth and changes in renewable energy consumption, in either direction. This suggests that alterations in renewable energy consumption do not serve as predictors for GDP growth, and conversely, GDP growth does not forecast changes in renewable energy consumption among the countries studied. This lack of significant causality implies that the elements influencing economic growth and renewable energy consumption operate independently within this context.

According to Table 19, the panel vector autoregression (PVAR) model satisfies the stability condition, with two significant coefficients but no Granger causality. In this case, the PVAR model's stability condition implies that there are long-term equilibrium relationships among the variables within the system. The significant coefficients indicate that certain explanatory variables have a substantial impact on the dependent variable, and these impacts are statistically reliable.

However, despite the significant coefficients, the absence of Granger causality means that within the considered time frame and model specification, the variables do not have the ability to predict each other. In other words, one variable cannot be used to predict the future values of another variable, at least not with statistically significant predictive power. Nonetheless, even in the absence of Granger causality, the significant coefficients may still have policy implications. For instance, in the context of low-income countries where past renewable energy consumption difference negatively impacts economic growth while past economic growth benefits current economic growth, policy recommendations should comprehensively consider the multiple objectives of promoting economic growth and improving the energy structure. For example, subsidies or tax incentives could be provided to reduce the cost of renewable energy; investments could be made in energy efficiency technologies to reduce energy consumption and improve energy use efficiency. Additionally, implementing sound macroeconomic policies to maintain stable economic growth is essential.

Table 19:

```
. pvarstable

   Eigenvalue stability condition
```

| Eigenvalue Real | Eigenvalue Imaginary | Modulus |
|---|---|---|
| .6569532 | 0 | .6569532 |
| -.3177172 | 0 | .3177172 |
| .066637 | -.3074166 | .3145559 |
| .066637 | .3074166 | .3145559 |

```
   All the eigenvalues lie inside the unit circle.
   pVAR satisfies stability condition.
```

In conclusion, for the hypothesis 2, the utilization of renewable energy is positively correlated with economic growth are not directly been supported. For the group of all 88 countries, economic growth tends to decrease the rate of increase in renewable energy consumption. This suggests a unidirectional causal relationship where economic growth influences changes in renewable energy consumption patterns rather than the other way around. Contrary to Hypothesis 2, this indicates that during periods of economic growth, the focus may shift away from renewable energy initiatives. In high-income countries, GDP growth negatively impacts renewable energy consumption changes. The Granger causality tests reveal a clear unidirectional relationship where GDP growth predicts changes in renewable energy consumption, but renewable energy consumption does not predict GDP growth. This finding suggests that economic expansion in high-income countries is associated with adjustments in renewable energy consumption, often reducing the emphasis on renewable energy. However, even if the renewable energy consumption differences do not show a direct significant impact on GDP growth, the overall economic structure and resources suggest a potential for long-term benefits from renewable energy investments. For middle-income countries, the negative impact of GDP growth on differences in renewable energy consumption further highlights the continued reliance on traditional energy sources. However, this finding may only reflect short-term economic phenomena, and without proper testing and adjustments for model stability, it may not be applicable for long-term economic analysis. In low-income countries, past changes in renewable energy consumption have a negative impact on current economic growth. This finding contradicts Hypothesis 2, as it suggests that increased renewable energy consumption does not foster economic growth; rather, economic growth depends on traditional energy sources, with insufficient investment in renewable energy to drive economic expansion.

In summary, the results do not directly support the hypothesis that the utilization of renewable energy is positively correlated with economic growth. During periods of low uncertainty and normal economic development, investments in renewable energy are unlikely to be considered (whether increasing or decreasing) because everything is already in place.

## 3.3 The relationship between World uncertainty index and Renewable energy consumption, subset for Oil export countries. (Preparation for testing hypothesis 3) (Method: Fixed effect model, Annual data)

Table 20：For all 88 countries:

```
. estimates table pooled fixed1 fixed2 fixed3, star stats(N r2 r2_a)
```

| Variable | pooled | fixed1 | fixed2 | fixed3 |
|---|---|---|---|---|
| RECDif | .00625865** | .0067514*** | .0067514** | .0067514** |
| G_lag1 | -.00411818*** | -.00375363*** | -.00375363*** | -.00375363*** |
| n | -.00197525 | .00263496 | .00263496 | .00263496 |
| TRADE | -.00019126** | .00109215*** | .00109215* | .00109215* |
| GOV | .00109223 | .00912728*** | .00912728** | .00912728** |
| CAP | -.00181045*** | .00138647* | .00138647 | .00138647 |
| _cons | .24486616*** | -.06538163 | -.06538163 | -.06538163 |
| N | 2112 | 2112 | 2112 | 2112 |
| r2 | .03643437 | .04142726 | .04142726 | .04142726 |
| r2_a | .03368787 | -.00274879 | .03869498 | .03869498 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

The empirical results for the relationship between renewable energy consumption (REC) and the World Uncertainty Index (WUI) across 88 countries are presented in Table 20. The table displays the results from four models: Pooled model (pooled), Fixed effect model (fixed1), Fixed effect model with clustered standard errors (fixed2), and Fixed effect model with both clustered standard errors and robust cross-sectional dependence correction (fixed3).

After controlling for heteroscedasticity, autocorrelation, and cross-sectional dependence, the fixed effect model with both clustered standard errors and robust cross-sectional dependence correction (fixed3) is most appropriate, the coefficient of difference of Renewable Energy Consumption (RECDif) is 0.0067514, which is statistically significant at 1% level. This indicates a strong positive relationship between the change in renewable energy consumption and world uncertainty, suggesting that an increase in changes of renewable energy consumption may increase the uncertainty. The past GDP growth rate has a negative and significant impact on current GDP growth rate, this might be because most of countries in the sample are high income countries. The adjusted R-squared indicating that approximately 3.9% of the variance in world uncertainty is explained by the model. Trade as percentage of GDP and government expenditure also show significant and positive impacts on world uncertainty, this suggests that countries with higher trade openness and increased government spending may be more sensitive to global uncertainty. Higher trade openness can increase a country's exposure to global economic fluctuations and uncertainties. Countries more integrated into the global economy might experience greater volatility due to international trade dynamics, geopolitical events, or global economic downturns. Similarly, increased government spending could exacerbate economic vulnerability and instability if it is not well-targeted or leads to large fiscal deficits. However, this may also indicate that as global uncertainty rises, governments might increase spending to stabilize the economy or support domestic industries affected by international market fluctuations. In this case, government spending could be a response to mitigate the impacts of global uncertainty rather than a cause of it. Gross capital formation's lack of significance in the fixed2 and fixed3 models suggests that its impact may be less straightforward or influenced by other factors not captured in the model.

Table 21: For High-income countries

```
. estimates table pooled fixed1 fixed2 fixed3, star stats(N r2 r2_a)
```

| Variable | pooled | fixed1 | fixed2 | fixed3 |
|---|---|---|---|---|
| RECDif | .01119368** | .00653148 | .00653148 | .00653148 |
| G_lag1 | -.00199772 | -.0025542 | -.0025542 | -.0025542 |
| n | .00212896 | -.01016564 | -.01016564 | -.01016564 |
| TRADE | -.0001352 | .00153328*** | .00153328 | .00153328 |
| GOV | .00164028 | .01874646*** | .01874646** | .01874646** |
| CAP | -.00088381 | .00375088* | .00375088 | .00375088 |
| _cons | .18847656*** | -.39774571*** | -.39774571* | -.39774571* |
| N | 816 | 816 | 816 | 816 |
| r2 | .02810911 | .08448284 | .08448284 | .08448284 |
| r2_a | .02090102 | .03847103 | .07769285 | .07769285 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

Table 22: For Middle income countries

```
. estimates table pooled fixed1 fixed2 fixed3, star stats(N r2 r2_a)
```

| Variable | pooled | fixed1 | fixed2 | fixed3 |
|---|---|---|---|---|
| RECDif | .00599382* | .00756902** | .00756902** | .00756902** |
| G_lag1 | -.00555591*** | -.0046955** | -.0046955** | -.0046955** |
| n | -.00362703 | .01151891 | .01151891 | .01151891 |
| TRADE | -.00051435*** | .0003224 | .0003224 | .0003224 |
| GOV | .00378154** | .00871213*** | .00871213* | .00871213* |
| CAP | -.00332374*** | .0005149 | .0005149 | .0005149 |
| _cons | .28829313*** | .03944704 | .03944704 | .03944704 |
| N | 1056 | 1056 | 1056 | 1056 |
| r2 | .08443639 | .03767526 | .03767526 | .03767526 |
| r2_a | .07919961 | -.00919742 | .03217102 | .03217102 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

Table 23: For Low-income countries

```
. estimates table pooled fixed1 fixed2 fixed3, star stats(N r2 r2_a)
```

| Variable | pooled | fixed1 | fixed2 | fixed3 |
|---|---|---|---|---|
| RECDif | .00099748 | .00123411 | .00123411 | .00123411 |
| G_lag1 | -.0017279 | -.00098117 | -.00098117 | -.00098117 |
| n | -.00738539 | -.00911722 | -.00911722 | -.00911722 |
| TRADE | .00155143** | .00212265* | .00212265 | .00212265 |
| GOV | -.00559165* | -.00131254 | -.00131254 | -.00131254 |
| CAP | .00322429* | .00334376 | .00334376 | .00334376 |
| _cons | .13224709** | .04885541 | .04885541 | .04885541 |
| N | 240 | 240 | 240 | 240 |
| r2 | .09134066 | .08162491 | .08162491 | .08162491 |
| r2_a | .06794171 | .02012658 | .05797577 | .05797577 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

For high income countries, the coefficient for RECDif in the pooled model is 0.01119368, which is statistically significant at the 1% level ($p \leq 0.01$). This suggests that in high income countries, an increase in the difference of renewable energy consumption is associated with a significant increase in world uncertainty. However, for the rest of fixed effect model which are more appropriate to use, the results are all insignificant. For middle income countries, the coefficient of renewable energy consumption is positive and statistically significant at 1% level. In the case of low-income countries, the coefficients for RECDif are insignificant for all the models, which does not reach conventional levels of statistical significance.

About the government expenditure, for high income countries and middle-income countries the coefficients are positive and significant. However, for low-income countries, the results are insignificant for the fixed effect model, highlighting differences in fiscal policy effectiveness.

The analysis reveals that the impact of renewable energy consumption differences on world uncertainty varies significantly across income groups. High-income countries show a significant relationship in the pooled model but not in the fixed effect model. Middle-income countries exhibit a strong positive relationship, indicating substantial uncertainty creates due to renewable energy transitions. Low-income countries do not show a significant relationship. These could be because 1) low-income countries may rely more on traditional energy sources rather than renewable energy, while high-income countries likely have a more diversified energy consumption structure, not solely dependent on renewable energy. This could result in the impact of RECDif on uncertainty not being significant. 2) High-income countries often have more mature markets and more comprehensive policy environments to support the development of renewable energy. In contrast, low-income countries may experience less noticeable impacts of changes in renewable energy consumption on uncertainty due to imperfect markets, inadequate policies, and lower levels of globalization. These findings emphasize the need for tailored policy approaches that consider the specific economic contexts and developmental stages of each country group.

Table 24: For Oil export countries[2]

[2] Oil export countries within the full 88 countries sample are showing in Appendix 1.

```
estimates table pooled fixed1 fixed2 fixed3, star stats(N r2 r2_a)
```

| Variable | pooled | fixed1 | fixed2 | fixed3 |
|---|---|---|---|---|
| RECDif | .00231208 | .0041979 | .0041979 | .0041979 |
| G_lag1 | -.00485933** | -.00439345* | -.00439345* | -.00439345* |
| n | -.00763266 | .03718405* | .03718405 | .03718405 |
| TRADE | -.00055062* | -.00065314 | -.00065314 | -.00065314 |
| GOV | .00503449 | .01350193** | .01350193* | .01350193* |
| CAP | -.00146607 | .00001494 | .00001494 | .00001494 |
| _cons | .20560609*** | -.01417505 | -.01417505 | -.01417505 |
| N | 240 | 240 | 240 | 240 |
| r2 | .10289994 | .09360498 | .09360498 | .09360498 |
| r2_a | .07979865 | .03290888 | .07026433 | .07026433 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

On a broad scale, based on the finding for full 88 countries sample, as global uncertainty increases, the change in renewable energy consumption also tends to increase. However, for countries as the mumbers of OPEC and OPEC+ with significant oil exports, this relationship between WUI and RECDif is no longer significant. This divergence can be explained through several economic perspectives: first, Oil-exporting countries have an economic structure heavily reliant on oil revenues. In periods of high global uncertainty, these nations might prioritize stabilizing their main income source over diversifying into renewable energy, thus weakening the positive correlation observed in the broader dataset. Second, the income generated from oil exports in these countries could mitigate the need to immediately shift towards renewable sources in response to global uncertainty. The financial cushion provided by oil revenues allows for a more gradual transition to renewable energy, decoupling the previously observed relationship between WUI and RECDif. Third, in oil-exporting countries, the opportunity cost of investing in renewable energy might be perceived as higher due to the immediate profitability of oil exports. Consequently, in times of uncertainty, these countries might double down on their oil sector, diverting potential investments away from renewable energy projects. Fourth, Oil-exporting countries often have established infrastructures and policies that favor fossil fuel extraction and consumption. This inertia can slow down the response to an increase in the World Uncertainty Index, making the shift towards renewable energy less pronounced and immediate compared to countries less dependent on oil exports.

In summary, while a positive correlation between global uncertainty (WUI) and difference of the renewable energy consumption (RECDif) is observed broadly, this trend is attenuated in oil-exporting countries due to their unique economic dependencies, opportunity costs, and infrastructural inertia. This indicates that the relationship between global uncertainty and renewable energy consumption is complex and influenced by a country's economic structure and dependency on fossil fuels.

## 3.4 World uncertainty index, Renewable energy consumption and Economic growth (test hypothesis 3) (Method: Fixed effect model, annual data)

After testing, the panels are cointegrated at the 1% significance level, indicating the presence of nonstationary. Therefore, although each individual time series may be nonstationary, there exists one or more stable long-term equilibrium relationships among them. This means that while the individual variables may exhibit trends or unit root behaviour, they are collectively interconnected in the long run. Additionally, the data demonstrate heteroscedasticity, meaning the variance of the error terms varies across observations. There is evidence of autocorrelation, indicating that the values within a time series are correlated with their past values. Lastly, there exists cross-sectional dependence, implying that there are interdependencies among the cross-sectional units in the panel data. These findings are consistent with the predictive analysis outlined in Section 2 Methodology part of the thesis.

## 3.4.1 Test the relationship between World uncertainty index, Renewable energy consumption and Economic growth by using interaction term (Method: Fixed effect model, annual data)

Table 25-28. These tables display the results from the following models, since the findings of testing before the Fixed 6,7,8 is appropriate to use:

Pooled: Pooled model,

Fixed 1: Fixed effect model without interaction term

Fixed 2: Fixed effect model with interaction term

Fixed 3: Fixed effect model with clustered standard errors without interaction term

Fixed 4: Fixed effect model with clustered standard errors with interaction term

Fixed 5, Fixed effect model with both clustered standard errors and robust cross-sectional dependence correction without interaction term

Fixed 6 Fixed effect model with both clustered standard errors and robust cross-sectional dependence correction with interaction term

Fixed 7: Fixed effect model with both clustered standard errors and robust cross-sectional dependence correction with interaction term, without variable RECDif.

Table 25: For All 88 countries

```
. estimates table pooled fixed1 fixed2 fixed3 fixed4 fixed5 fixed6 fixed7, star stats(N r2 r2_a)
```

| Variable | pooled | fixed1 | fixed2 | fixed3 | fixed4 | fixed5 | fixed6 | fixed7 |
|---|---|---|---|---|---|---|---|---|
| WUI | -3.1484143*** | -3.5354074*** | -3.1377505*** | -3.5354074*** | -3.1377505*** | -3.5354074*** | -3.1377505*** | -3.1265844*** |
| RECDif | -.30246627*** | -.26353771*** | -.02225713 | -.26353771*** | -.02225713 | -.26353771*** | -.02225713 | |
| G_lag1 | .31842415*** | .19402857*** | .19400498*** | .19402857** | .19400498** | .19402857** | .19400498** | .19404453** |
| n | .21881399** | .2245114 | .21685309 | .2245114 | .21685309 | .2245114 | .21685309 | .21684421 |
| TRADE | .00106616 | .02300231*** | .02348263*** | .02300231*** | .02348263*** | .02300231*** | .02348263*** | .02352361*** |
| GOV | -.10956211*** | -.33509704*** | -.32517345*** | -.33509704*** | -.32517345*** | -.33509704*** | -.32517345*** | -.32542487*** |
| CAP | .06460354*** | .10212216*** | .10481831*** | .10212216** | .10481831*** | .10212216** | .10481831*** | .10518502** |
| WUI_RECDif | | | -1.453877*** | | -1.453877*** | | -1.453877*** | -1.5262151*** |
| _cons | 2.5271796*** | 3.9201049*** | 3.6314385*** | 3.9201049* | 3.6314385* | 3.9201049* | 3.6314385* | 3.623088* |
| N | 2112 | 2112 | 2112 | 2112 | 2112 | 2112 | 2112 | 2112 |
| r2 | .23943497 | .16845343 | .17733425 | .16845343 | .17733425 | .16845343 | .17733425 | .17729349 |
| r2_a | .23690457 | .12970014 | .13856776 | .16568688 | .17420476 | .16568688 | .17420476 | .17455635 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

According to Table 25, for all 88 countries, the WUI (World Uncertainty Index) exhibits a consistently negative and highly significant relationship with GDP growth across all models ($p < 0.01$). A higher WUI, indicative of greater global uncertainty, is associated with a reduction in GDP growth. This finding is consisting with the finding in section 3.1 that using PVAR model and quarterly data. This result implying that an increase in the World Uncertainty Index independently depresses economic growth, irrespective of changes in renewable energy consumption. The coefficient for RECDif (Renewable Energy Consumption Differenced) is negative and it maintains significance in most cases, indicating that the first difference of renewable energy consumption, in isolation from changes in WUI, has a detrimental impact on economic growth within the model's framework. Explanations might distort the observed results: 1) Renewable energy technologies, such as solar and wind power, usually require high initial investments. These investments might reduce the funds available for other economic activities in the short term, thereby impacting GDP growth. 2)If a country heavily invests in renewable energy, it might reduce its reliance on traditional energy sources like coal and oil. Since the traditional energy sector occupies a significant position in many countries, this shift could have a short-term negative impact on GDP. 3)The efficiency of renewable energy might not be as high as fossil fuels. For instance, the capacity utilization rates of solar and wind energy are often lower than those of fossil fuel power plants. This could lead to increased production costs, thereby affecting economic growth. And renewable energy technology is still evolving and may not yet be optimized. This means that its direct contribution to the economy could be limited until the technology matures. 4)There are multiple motives because countries are trying to get into renewables, but so far it seems that the higher share of renewables is typical for the richest, most developed countries. These are also the countries which are not expected, or which typically are not growing too fast. So, partly because they are already rather developed, so they are not following in anybody's footsteps, so their growth would be expected to be lower.

They are not catching up. 5) In the energy sector, transitioning the supply of energy from reliance on traditional sources such as coal and oil to renewable sources like wind and solar power is a classic example of creative destruction. For instance, in the Czech Republic or Germany, governments and businesses are closing facilities based on traditional energy and investing in infrastructure for renewable energy. Although this process may lead to the demise of some old industries or businesses, it will ultimately promote economic innovation and development. During the energy transition, investment in renewable energy infrastructure can be seen to increase government or economic expenditure, which theoretically should stimulate economic growth (Keynesian effect). However, this transition also presents some challenges, especially regarding the direction of funds. When a country invests heavily in renewable energy, if many components of these investments (like solar panels or wind turbines) need to be imported, this will lead to capital flowing out of the domestic economy to the countries manufacturing these devices, such as China, India, or Thailand. This outflow of funds can be seen as a "leakage" because it reduces investment in domestic production and may weaken the positive impact of the energy transition on domestic economic growth. Therefore, while the shift from traditional to renewable energy has its positive economic impacts, such as promoting economic innovation and development through creative destruction and stimulating economic growth through the Keynesian effect, this process also faces challenges like capital flowing abroad. This could diminish the positive impact of this transition on economic growth. Such findings are not inconsistent with those in Section 3.2 which identified a negative unidirectional causality from economic growth to REC difference.

The coefficient for the WUI_RECDif interaction term is -1.45, and it is highly significant at 0.1% level. If we take the findings that there is a positive relationship between renewable energy consumption and economic growth as a prerequisite, as found in many previous studies such as Chen et al. (2020), Ozcan and Ozturk (2019), and Doytch and Narayan (2021)， this negative coefficient suggests that during periods of elevated uncertainty, the growth-promoting impact of renewable energy consumption on GDP may be attenuated or even become inhibitory. This could be due to an increase in risk-averse behaviors, a rise in the cost of capital, or insufficient policy and market support during periods of high uncertainty.

If we consider the finding that there is a negative relationship between renewable energy consumption and economic growth as a prerequisite, as found in many previous studies such as Alqaralleh and Hatemi-J (2023) and Ocal and Aslan (2013). The negative coefficient for the interaction term suggests that the adverse effect of renewable energy consumption on economic growth is exacerbated during periods of high economic uncertainty. This means that in uncertain times, the shift to renewable energy may further strain the economy, possibly due to heightened risk aversion, increased costs, or slower investment in new technologies.

Regarding the explanation of control variables, it is centralized here, and this will not provide detailed explanations unless there are special noteworthy circumstances.

- G_lag1 (Lagged GDP Growth Rate): The positive and significant coefficients for the lagged GDP growth rate at 1% significant level ($p < 0.01$) across all models indicate a persistence effect in economic growth. This signifies that past economic performance is a strong predictor of future growth, highlighting the importance of maintaining growth momentum. This finding is consisting with the findings in Section 3.1 and 3.2.
- n (Population Growth Rate): The population growth rate presents a positive correlation with GDP growth in most models but is statistically insignificant except for pool model.

- TRADE (Trade as a Percentage of GDP): The trade variable is consistently positive and statistically significant at 0.1% level ($p < 0.01$), suggesting that a higher level of trade openness is correlated with an increase in GDP growth. This supports the economic theory that trade openness facilitates efficiency gains and access to larger markets, thereby promoting growth.
- GOV (Government Expenditure): Government expenditure is negatively correlated with GDP growth and is significant in all models at 0.1% significant level ($p < 0.01$). This could imply that, within this dataset, government spending is inefficient or crowding out private sector activity, which could be detrimental to economic growth.
- CAP (Gross Capital Formation): The gross capital formation presents a positive and significant effect in models ($p < 0.01$). This finding shows capital formation is a driver of economic growth.

Table 26: For High-income countries

```
. estimates table pooled fixed1 fixed2 fixed3 fixed4 fixed5 fixed6 fixed7, star stats(N r2 r2_a)
```

| Variable | pooled | fixed1 | fixed2 | fixed3 | fixed4 | fixed5 | fixed6 | fixed7 |
|---|---|---|---|---|---|---|---|---|
| WUI | -3.0590317*** | -3.547456*** | -2.2023849* | -3.547456*** | -2.2023849* | -3.547456*** | -2.2023849* | -2.2068579* |
| RECDif | -.40304354*** | -.35591518*** | .00185873 | -.35591518** | .00185873 | -.35591518** | .00185873 | |
| G_lag1 | .23286401*** | .01179483 | .00720967 | .01179483 | .00720967 | .01179483 | .00720967 | .00721848 |
| n | -.02343359 | -.84568224*** | -.86590619*** | -.84568224* | -.86590619* | -.84568224* | -.86590619* | -.86580174* |
| TRADE | .00152916 | .01812426*** | .01876446*** | .01812426 | .01876446* | .01812426 | .01876446* | .01876398* |
| GOV | -.08849176** | -.79022047*** | -.79667109*** | -.79022047*** | -.79667109*** | -.79022047*** | -.79667109*** | -.79657956*** |
| CAP | .15337045*** | .26037186*** | .27366136*** | .26037186* | .27366136** | .26037186* | .27366136** | .27361255** |
| WUI_RECDif | | | -1.8309887** | | -1.8309887** | | -1.8309887** | -1.8245061*** |
| _cons | .28562507 | 10.248096*** | 9.7871319*** | 10.248096 | 9.7871319 | 10.248096 | 9.7871319 | 9.7875231 |
| N | 816 | 816 | 816 | 816 | 816 | 816 | 816 | 816 |
| r2 | .22996562 | .29555845 | .30302182 | .29555845 | .30302182 | .29555845 | .30302182 | .30302168 |
| r2_a | .22329453 | .25920018 | .26610179 | .28945561 | .29611249 | .28945561 | .29611249 | .2969835 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

Table 27: For Middle-income countries

. estimates table pooled fixed1 fixed2 fixed3 fixed4 fixed5 fixed6 fixed7, star stats(N r2 r2_a)

| Variable | pooled | fixed1 | fixed2 | fixed3 | fixed4 | fixed5 | fixed6 | fixed7 |
|---|---|---|---|---|---|---|---|---|
| WUI | -2.4900647*** | -2.5616367*** | -2.4917562*** | -2.5616367*** | -2.4917562*** | -2.5616367*** | -2.4917562*** | -2.4475039*** |
| RECDif | -.24511475*** | -.18340122** | .11227375 | -.18340122* | .11227375 | -.18340122* | .11227375 | |
| G_lag1 | .38517425*** | .27443749*** | .27254289*** | .27443749** | .27254289** | .27443749** | .27254289** | .27256812** |
| n | -.01851532 | .24631712 | .23950954 | .24631712 | .23950954 | .24631712 | .23950954 | .23245431 |
| TRADE | .0056133 | .0402296*** | .04043348*** | .0402296** | .04043348** | .0402296** | .04043348** | .04009622** |
| GOV | -.13560473*** | -.3266044*** | -.314161*** | -.3266044** | -.314161** | -.3266044** | -.314161** | -.31123506** |
| CAP | .04925343*** | .06020737** | .06458076** | .06020737 | .06458076 | .06020737 | .06458076 | .06253313 |
| WUI_RECDif | | | -1.8601969*** | | -1.8601969** | | -1.8601969** | -1.5076253*** |
| _cons | 2.8836244*** | 2.87725* | 2.6291806* | 2.87725 | 2.6291806 | 2.87725 | 2.6291806 | 2.6430951 |
| N | 1056 | 1056 | 1056 | 1056 | 1056 | 1056 | 1056 | 1056 |
| r2 | .24879562 | .19502916 | .21255601 | .19502916 | .21255601 | .19502916 | .21255601 | .2112946 |
| r2_a | .24377803 | .15498086 | .17255636 | .18965244 | .20653925 | .18965244 | .20653925 | .20602653 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

Table 28: For Low-income countries

. estimates table pooled fixed1 fixed2 fixed3 fixed4 fixed5 fixed6 fixed7, star stats(N r2 r2_a)

| Variable | pooled | fixed1 | fixed2 | fixed3 | fixed4 | fixed5 | fixed6 | fixed7 |
|---|---|---|---|---|---|---|---|---|
| WUI | -5.8544031** | -5.8085591** | -5.9175862** | -5.8085591 | -5.9175862 | -5.8085591 | -5.9175862 | -5.6598832 |
| RECDif | -.35418323* | -.32405071* | -.41217633 | -.32405071 | -.41217633 | -.32405071 | -.41217633 | |
| G_lag1 | .15641075* | .06871627 | .06715969 | .06871627 | .06715969 | .06871627 | .06715969 | .06848603 |
| n | .90010675** | 1.0784558** | 1.0840627** | 1.0784558* | 1.0840627* | 1.0784558* | 1.0840627* | 1.0625092* |
| TRADE | .01569738 | .05616828 | .05909143 | .05616828 | .05909143 | .05616828 | .05909143 | .05293119 |
| GOV | .04476466 | .15893374 | .14961789 | .15893374 | .14961789 | .15893374 | .14961789 | .18440503 |
| CAP | .09479102* | .07664913 | .07507916 | .07664913 | .07507916 | .07664913 | .07507916 | .08236666 |
| WUI_RECDif | | | .54902365 | | .54902365 | | .54902365 | -.98533662 |
| _cons | -1.1217647 | -4.3004868 | -4.2841636 | -4.3004868 | -4.2841636 | -4.3004868 | -4.2841636 | -4.4846255 |
| N | 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 |
| r2 | .14703592 | .13427903 | .13525183 | .13427903 | .13525183 | .13427903 | .13525183 | .12253618 |
| r2_a | .12129994 | .07216452 | .06903237 | .10815814 | .10530384 | .10815814 | .10530384 | .09606098 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

Comparing the Table 26,27 and 28, for Low-income countries, the coefficients for WUI and RECDif are insignificant. For high-income countries, the coefficients for WUI and RECDif are statistically significant at 5% level. For middle-income countries, when the coefficient for RECDif turns from negative to positive upon including the WUI_RECDif interaction term, it implies that the influence of renewable energy consumption differentials on economic growth is contingent upon the level of global uncertainty.

Here's the rationale for this occurrence:1) Without the Interaction Term, the negative coefficient for RECDif suggests that ceteris paribus, increases in difference of renewable energy consumption are correlated with economic depression. With the Interaction Term, a negative coefficient for this interaction term intimates that an escalation in uncertainty could mitigate or negate the positive contribution of renewable energy consumption to economic growth.2) The beneficial influence of renewable energy consumption on economic growth might only be evident under a climate of low global uncertainty. With heightened uncertainty, these benefits could diminish due to an increase in risk-averse investment behavior, a rise in the cost of capital, or other market dislocations associated with elevated uncertainty. Renewable energy investments may necessitate stable economic conditions to exert a positive impact on economic growth. In times of high uncertainty, these prerequisites may not be met, leading to adverse effects.

Overall, to further explore the inquiry in Hypothesis 3—whether the impact of renewable energy consumption disparities on economic growth is influenced by the degree of global uncertainty—this study will employ two approaches to test this conjecture. 1) Using dummy variables for data analysis. 2) Analyzing the data by distinguishing between high and low uncertainty situations.

## 3.4.2 Dummy variables

Since there are different coefficient for include or exclude interaction term and in comparing the results for different country groups, the beneficial impact of renewable energy consumption on economic growth may be influenced by the level of uncertainty. The relationship in Scatter plot for RECDif and WUI*RECDif (Figure 1) shows that, it is reasonable to include High World uncertainty and Low world uncertainty dummies in the analysis which is drawing the inspiration from the research on uncertainty and crime by Goulas and Zervoyianni (2013).
Figure 1:

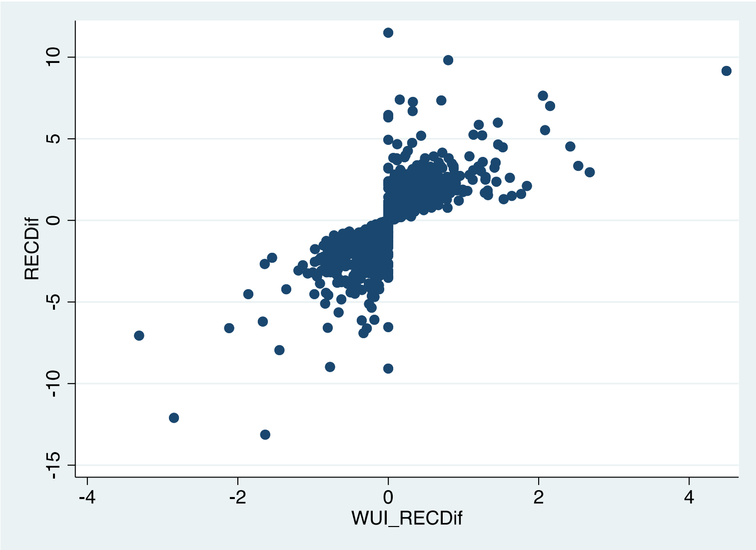


Table 29 contains all the results using dummy variables and a relatively appropriate base model: the fixed effect model with both clustered standard errors and robust cross-sectional dependence correction.

All_HU: For all countries group, under conditions of high uncertainty

All_LU: For all countries group, under conditions of low uncertainty

High_HU: For high income countries group, under conditions of high uncertainty

High_LU: For high income countries group, under conditions of low uncertainty

Middle_HU: For middle income countries group, under conditions of high uncertainty

Middle_LU: For middle income countries group, under conditions of low uncertainty

Low_HU: For low-income countries group, under conditions of high uncertainty

Low_LU: For low-income countries group, under conditions of low uncertainty

Table 29:

```
.
. estimates table All_HU All_LU High_HU High_LU Middle_HU Middle_LU Low_HU Low_LU, star stats(N r2 r2_a)
```

| Variable | All_HU | All_LU | High_HU | High_LU | Middle_HU | Middle_LU | Low_HU | Low_LU |
|---|---|---|---|---|---|---|---|---|
| WUI | -3.419192*** | -3.419192*** | -3.067297** | -3.067297** | -2.821754*** | -2.821754*** | -5.8620818 | -5.8620818 |
| RECDif | -.06428479 | -.59782163*** | -.21347804 | -.52297557** | .04791327 | -.61104488*** | -.21664135 | -.51600776 |
| HU_RECDif | -.53353684*** | | -.30949753 | | -.65895815*** | | -.29936641 | |
| G_lag1 | .19302813** | .19302813** | .01186605 | .01186605 | .27373618** | .27373618** | .06767756 | .06767756 |
| n | .21589384 | .21589384 | -.83664509* | -.83664509* | .22247798 | .22247798 | 1.0735318* | 1.0735318* |
| TRADE | .02356599*** | .02356599*** | .01831942 | .01831942 | .04076875** | .04076875** | .04927721 | .04927721 |
| GOV | -.32019485*** | -.32019485*** | -.78718431*** | -.78718431*** | -.3072444** | -.3072444** | .17044905 | .17044905 |
| CAP | .10492746*** | .10492746*** | .26049864* | .26049864* | .0682783* | .0682783* | .08025432 | .08025432 |
| LU_RECDif | | .53353684*** | | .30949753 | | .65895815*** | | .29936641 |
| _cons | 3.605074* | 3.605074* | 10.081122 | 10.081122 | 2.5147149 | 2.5147149 | -4.1507142 | -4.1507142 |
| N | 2112 | 2112 | 816 | 816 | 1056 | 1056 | 240 | 240 |
| r2 | .18136339 | .18136339 | .29873542 | .29873542 | .21582385 | .21582385 | .13818748 | .13818748 |
| r2_a | .17824922 | .17824922 | .2917836 | .2917836 | .20983205 | .20983205 | .10834116 | .10834116 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

In the Table 29, for all countries group and middle-income countries, the coefficient for the interaction term HU_RECDif is negative (-0.534; -0.659) and statistically significant at 0.1% level ($p < 0.001$). This suggests that under conditions of high uncertainty (High Uncertainty, HU=1), the impact of the first difference of Renewable Energy Consumption (RECDif)—which is the difference between the current period's Renewable Energy Consumption (REC) and the previous period's REC—on the GDP growth rate is negatively reinforced. If the RECDif is positive (meaning there is an increase in REC from the previous period), high uncertainty tends to weaken the positive impact this increase might have on GDP growth. Conversely, if the RECDif is negative (indicating a decrease in REC from the previous period), high uncertainty appears to amplify the adverse effect this decrease could have on GDP growth. The coefficient for LU_RECDif is positive (0.534; 0.659) and statistically significant at 0.1% level. Since low uncertainty (Low Uncertainty, LU=0) serves as the baseline, the positive coefficient here indicates that under low uncertainty, an increase in RECDif could have an enhanced positive impact on GDP growth. That is, when REC increases from one period to the next, low uncertainty may amplify the positive effect of this increase on GDP growth. If RECDif is negative, low uncertainty may soften the potential negative impact on GDP growth. However, for high income countries and low-income countries, the results are both insignificant.

Notably, while the coefficients for the interaction terms in both models are numerically identical, they bear opposite signs. This highlights that the level of uncertainty (be it high or low) modifies the effect of changes in Renewable Energy Consumption on GDP growth but in divergent directions. This might imply that uncertainty indeed affects the efficacy of changes in REC on economic growth, where high uncertainty exacerbates the negative outcomes of a reduction in REC on GDP growth, and low uncertainty could potentially enhance the positive outcomes of an increase in REC on GDP growth.

However, by distinguishing between high and low uncertainty situations and separately examining the relationship between REC and G in each context, the partially different conclusion can be found.

### 3.4.3 Test the relationship between Renewable energy consumption and Economic growth in high and low uncertainty situation. (Method: Fixed effect model, annual data)

The estimation is renewable energy investments may necessitate stable economic conditions to exert a positive impact on economic growth. In times of high uncertainty, these prerequisites may not be met, leading to adverse effects. However, the reality is that investment in renewable energy is not a necessity; Higher uncertainty can foster greater changes in REC (Renewable Energy Consumption). Most countries do not rely on it to stimulate economic growth. Therefore, it requires external stimuli to respond, such as during periods of high global uncertainty.

Table 30 and 31 display the results from the relatively appropriate base model: fixed effect model with both clustered standard errors and robust cross-sectional dependence correction.

For Table 30:

All_L: For all countries group, under conditions of low uncertainty

High_L: For high income countries group, under conditions of low uncertainty

Middle_L: For middle income countries group, under conditions of low uncertainty

Low_L: For low-income countries group, under conditions of low uncertainty

For Table 31:

All_H: For all countries group, under conditions of high uncertainty

High_H: For high income countries group, under conditions of high uncertainty

Middle_H: For middle income countries group, under conditions of high uncertainty

Low_H: For low-income countries group, under conditions of high uncertainty

Table 30: For Low uncertainty situation:

```
. estimates table All_L High_L Middle_L Low_L, star stats(N r2 r2_a)
```

| Variable | All_L | High_L | Middle_L | Low_L |
|---|---|---|---|---|
| RECDif | -.06344337 | -.156077 | .03807348 | -.14075045 |
| G_lag1 | .17034685* | -.00900755 | .25671787* | -.02242167 |
| n | .09532533 | -1.4964778** | -.07010447 | 1.03563* |
| TRADE | .02655914** | .02915877* | .0549646*** | .06520324 |
| GOV | -.2430151* | -.66453627* | -.27339296 | .22655882 |
| CAP | .0914744** | .3956877*** | .03188483 | .04682575 |
| _cons | 2.4079769 | 3.0719285 | 2.290132 | -4.728617 |
| N | 1241 | 479 | 605 | 157 |
| r2 | .10985318 | .26506156 | .17164812 | .10467396 |
| r2_a | .10552507 | .25571912 | .1633369 | .06886092 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

In the Low Uncertainty situation, no matter for all 88 countries, for high income countries, for middle income countries nor for low-income countries, the insignificant negative coefficient of RECDif suggests that an increase in renewable energy consumption from one period to the next does not associate with economic growth in low uncertainty environments. In low uncertainty contexts, the incentive of investment in renewable energy is low since it is not a solution for solving some existing problem or diverting people's attention and investment in REC may not directly translate into immediate economic growth due to factors such as the long gestation period for returns on renewable projects, the initial cost of renewable technology, or the transition phase from traditional to renewable energy sources.

Table 31: For High uncertainty situation:

```
. estimates table All_H High_H Middle_H Low_H, star stats(N r2 r2_a)
```

| Variable | All_H | High_H | Middle_H | Low_H |
|---|---|---|---|---|
| RECDif | -.65043356*** | -.52915426** | -.65423755*** | -.68505353 |
| G_lag1 | .16653737** | -.00714747 | .2102918** | .11659867 |
| n | .41673636** | .62454367 | .38227726** | 1.12988 |
| TRADE | .0200575 | -.00825483 | .02101245 | .1103954 |
| GOV | -.49429786*** | -1.3612191*** | -.39985616** | -.04362964 |
| CAP | .14886834* | .06111323 | .18631852 | -.0463962 |
| _cons | 4.4633793 | 27.213993** | 1.4122413 | -4.8460084 |
| N | 871 | 337 | 451 | 83 |
| r2 | .22181361 | .353896 | .23417981 | .19099644 |
| r2_a | .21640954 | .34214865 | .22383089 | .12712773 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

The negative and statistically significant coefficient for RECDif in high uncertainty contexts for all countries group， high income countries, and middle income countries, indicates a clear inverse relationship between the change in renewable energy consumption (increase or decrease) and economic growth. Combine the findings in Section 3.3， this suggests that, when uncertainty is high, the increase in changes of renewable energy consumption may correlate with lower economic growth rates since the renewable energy consumption difference itself will leads to uncertainty and higher uncertainty brings negative impact on GDP growth rate . This is consistent with the findings in section 3.4.1 since high uncertainty can hinder economic growth as it might freeze investment, increase saving behavior over consumption, and lead to more cautious business practices. The additional investment in renewable energy during such times could place a strain on the economy, as funds may be diverted from other productive uses or consumption. Moreover, the uncertainty may amplify the risks associated with the capital-intensive nature of renewable energy projects, leading to a more pronounced negative impact on economic growth.

# 4. Discussion

The empirical findings of this study contribute significantly to the understanding of the relationship between global uncertainty, renewable energy consumption, and economic growth. The results reveal complex interactions among these variables, relatively aligning with discussions in the existing literatures in this field.

Firstly, regarding the World Uncertainty Index and economic growth, the results relatively validate Hypothesis 1, indicating a negative correlation between global uncertainty and economic growth, with this effect being more pronounced in high-income countries. This finding aligns with literature suggesting that increased uncertainty impedes economic activity by discouraging investment and reducing consumption (Bernanke, 1983; Bloom, Bond, and Van Reenen, 2007; Wang et al., 2014; Bannigidadmath et al., 2024). Additional references like Scheffel (2016), Carrière-Swallow and Céspedes (2013), Gaibulloe and Sandler (2008), Soybilgen et al. (2019), and Soltani et al. (2021) support this view. These findings are significant for policymakers, who should consider strategies to mitigate uncertainty to promote economic stability and growth. Future research could explore the underlying mechanisms causing these differences among income groups and identify specific policies to address these disparities. The existence of bidirectional causality suggests that uncertainty not only reduces economic growth but that economic downturns can also increase uncertainty, thereby creating cyclical impacts. This dynamic interdependence highlights the stabilizing role that policy measures can play in mitigating the effects of uncertainty.

Secondly, regarding the relationship between renewable energy consumption and economic growth, the findings partially validate Hypothesis 2, indicating that economic growth can influence renewable energy consumption, though the reverse may not necessarily be true. This stands in stark contrast to some literature that predicts a bidirectional relationship (Bhattacharya et al., 2016). The results across all nations, particularly high and middle-income countries, show that GDP growth predicts changes in renewable energy consumption, but not vice versa. This suggests that economic growth drives changes in renewable energy consumption, which implies significant adjustments in renewable energy consumption patterns during periods of economic expansion. In low-income countries, however, the results indicate no significant Granger causality in either direction between GDP growth and renewable energy consumption, suggesting that the factors driving economic growth and renewable energy consumption are largely independent in these contexts. Such findings lend some support to the neutrality hypothesis (Payne, 2009; Ozcan and Ozturk, 2019) and align with the mixed and contradictory results found in different countries regarding the causal relationship between renewable energy consumption and economic growth as observed by Ocal and Aslan (2013). Furthermore, the direct impact of renewable energy on economic growth appears limited, and its role within economic frameworks seems to depend more on existing economic structures.

Thirdly, regarding Hypothesis 3, the relationship among renewable energy consumption, uncertainty, and economic growth, the empirical findings offer nuanced insights. It is evident that the relationship between the use of renewable energy and its impact on uncertainty and economic stability is more intricate.

The analysis suggests that renewable energy does not have a direct causal impact on reducing uncertainty. According to results from the full sample, changes in renewable energy consumption tend to increase as global uncertainty rises. Such findings are consistent with those reported in the literature by Wei et al. (2021) and Chu & Le (2021). For countries that are major oil exporters, this relationship ceases to be significant.

Empirical results using dummy variables indicate that under conditions of high uncertainty, the difference in Renewable Energy Consumption (REC) negatively reinforces the impact on GDP growth rates. If REC increases from one period to the next, high uncertainty tends to weaken the potential positive effects this growth could have on GDP. Conversely, if REC decreases from one period to the next, high uncertainty seems to amplify the adverse effects this decline could have on GDP growth. Under conditions of low uncertainty, an increase in REC from one period to the next may enhance its positive impact on GDP growth, while a negative REC difference might mitigate potential negative impacts on GDP growth. This suggests that uncertainty indeed affects the efficacy of REC changes on economic growth, where high uncertainty exacerbates the negative impact of a reduction in REC on GDP growth, and low uncertainty may enhance the positive outcomes of an increase in REC.

In environments differentiated by levels of uncertainty, for low uncertainty contexts, the difference in renewable energy consumption appears to be unrelated to economic growth. In contexts of high uncertainty, there is a clear inverse relationship between changes in renewable energy consumption and economic growth.

As observed in Section 3.4, under conditions of high uncertainty, an increase in changes in renewable energy consumption may be associated with lower rates of economic growth, as the REC difference itself can induce uncertainty, which in turn negatively affects GDP growth. In summary, the relationship between global uncertainty and renewable energy consumption is complex, influenced by a country's economic structure, dependency on fossil fuels, and the degree of uncertainty.

In contrast to Hypothesis 3, the study finds that uncertainty indeed acts as a key factor influencing the benefits of renewable energy on economic growth, aligning with the first part of Hypothesis 3. This suggests that the level of uncertainty largely determines the extent to which renewable energy can promote economic growth. In fact, in environments of high uncertainty, an increase in renewable energy consumption may be associated with decreased economic growth, indicating that during periods of high uncertainty, investments in and utilization of renewable energy could be adversely impacted by economic pressures, potentially exacerbating economic instability. Furthermore, an increase in renewable energy consumption in low uncertainty environments may enhance its positive impact on GDP growth, while in high uncertainty environments, it could weaken or even translate into a negative effect. This contradicts the hypothesis that increased renewable energy consumption would generally mitigate the adverse effects of uncertainty.

In summary, these findings suggest that in promoting renewable energy policies, greater attention needs to be paid to the external economic environment and levels of uncertainty, as well as how these factors affect the economic outcomes of investments in renewable energy. Policymakers should consider the specific levels and dynamic changes in uncertainty when designing and implementing policies to increase the use of renewable energy, to ensure that these policies perform effectively across various economic conditions. Additionally, this implies that renewable energy policies need to possess flexibility and adaptability to address different economic fluctuations and conditions of uncertainty.

# 5. Limitations

This research encompasses multiple nations, thereby reflecting a unified trend across all studied countries; however, there remain nations that benefit from uncertainty. Given the significant differences in how countries perform under uncertainty, future research could benefit from focusing on individual nations or specific regions for in-depth case studies. This approach would facilitate a deeper understanding of how particular economic and policy environments influence the relationship between uncertainty, economic growth, and renewable energy consumption. Such single-country studies could provide insights that are more targeted for policy formulation and may reveal complex dynamics overlooked in multi-country analyses.

Due to constraints in data availability, my study predominantly utilized annual data, which may not capture the nuances of uncertainty as effectively as higher frequency data. Thus, future research should consider employing quarterly or even monthly data to more accurately assess the immediate impacts of uncertainty and potentially uncover short-term economic behaviors and reactions not observed previously. The use of high-frequency data would also enhance the timeliness and relevance of model predictions.

The inconsistencies between my findings and some existing literature suggest that adjustments may be needed in the theoretical framework or empirical models. In examining the relationship between RECDif and economic growth in middle-income countries, the panel vector autoregression (PVAR) model may reveal some significant coefficients, indicating possible short-term dynamic relationships between variables. However, the PVAR model does not satisfy the stability condition. Therefore, future research should conduct appropriate tests and adjustments for model stability to provide reliable support for long-term economic analysis. Future research could also explore alternative theoretical interpretations, test new or modified models to better align with observed data, and possibly introduce new variables, consider additional control variables, or employ different econometric techniques to explore the dynamics between variables.

The full dataset of this paper includes 88 countries, selected based on the absence of missing data. The dataset is predominantly composed of developed countries or high-income countries, which means that the results are more reflective of this group. In testing the relationship between WUI and EG, quarterly data was used. Due to data availability constraints, high-income countries were the most represented, while no low-income countries were included. Consequently, the empirical conclusions are more indicative of high-income countries and lack representativeness for low-income countries. Future research could consider focusing on a single type of country or strive to include a wider variety of countries to make the findings more representative.

Through empirical research, it is necessary to acknowledge that the relationship between global uncertainty and renewable energy consumption is complex and influenced by factors such as a country's economic structure and dependence on fossil fuels. Future studies could target specific groups of countries for detailed analysis, leading to more precise findings that are applicable to types of countries, thereby providing more tailored policy recommendations.

# Conclusion

This study has explored the intricate relationships among global uncertainty, renewable energy consumption, and economic growth across a diverse set of 88 countries, employing a robust empirical framework including the PVAR model and fixed effects models. The findings provide comprehensive insights that refine and support our hypotheses, offering significant implications for policy and future research.

Hypothesis 1 posited that economic growth decreases as uncertainty increases. Our analysis, across all models—PVAR model, pooled, fixed effect, fixed effect with clustered standard errors, and fixed effect with both clustered standard errors and robust cross-sectional dependence correction—consistently demonstrates a negative and statistically significant relationship between the World Uncertainty Index (WUI) and GDP growth. The relationship is even dynamic interdependence between two variables. This robust finding underscores the detrimental impact of heightened global uncertainty on economic performance, aligning with previous research indicating that uncertainty reduces investment, consumption, and overall economic activity. Particularly in high-income countries, the negative effect of uncertainty on GDP growth is more pronounced, emphasizing the importance of stable economic environments in fostering sustained growth.

Hypothesis 2 suggested that the use of renewable energy facilitates economic growth. Our findings partially support this hypothesis. While renewable energy consumption shows positive associations with GDP growth, particularly in high-income countries where technological advancements and infrastructure investments are more pronounced, the causal relationship is nuanced. The economic benefits of renewable energy adoption may be hindered by initial high costs and technological inefficiencies, especially in transitioning economies. This highlights the importance of targeted policies and investments to maximize the economic benefits of renewable energy transitions.

Hypothesis 3, which proposed that uncertainty influences the extent to which renewable energy benefits economic growth, and that renewable energy consumption can mitigate the negative impact of uncertainty on growth, finds mixed support in our analysis. The interaction term between WUI and changes in renewable energy consumption (RECDif) reveals complex dynamics. During periods of high uncertainty, the positive impact of renewable energy consumption on GDP growth diminishes, suggesting that uncertainty exacerbates the economic challenges associated with renewable energy transitions. Conversely, in stable economic environments, increasing renewable energy consumption can potentially mitigate the negative effects of uncertainty on economic growth. This underscores the need for adaptive policies that can harness the synergies between renewable energy adoption and economic stability.

Moreover, our study identifies several key determinants of economic growth. Past GDP growth rates negatively impact current growth rates, indicative of economic inertia or cyclical effects that can hinder momentum. Trade and government expenditure consistently exhibit positive impacts on GDP growth, underscoring their crucial roles in driving economic performance and fostering development. The impact of capital formation on GDP growth, however, varies across different models, suggesting that there are contextual dependencies and specific conditions under which capital investment may or may not be effective. These variations highlight the need for further investigation into the nuanced factors influencing capital formation's role in economic growth. Additionally, understanding these determinants can help policymakers tailor strategies to enhance growth in varying economic environments.

In conclusion, this study provides empirical evidence on the complex interplay among global uncertainty, renewable energy consumption, and economic growth. The findings highlight the critical role of stable economic environments in fostering the positive impacts of renewable energy transitions and mitigating the adverse effects of uncertainty. Policymakers should consider these dynamics in designing resilient policies that promote sustainable economic development. Additionally, integrating renewable energy into national energy policies can help buffer economies against global uncertainties. Future research should further explore these relationships, particularly in diverse economic contexts and with different methodological approaches, to provide nuanced insights and tailored policy recommendations. This will ensure that policies are well-informed and effectively address the unique challenges and opportunities of each economic landscape.

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# Appendices:

Appendix 1(The Word Bank, 2024; OPEC, 2024 and EIA, 2024).

| Country Groups | | | | |
|---|---|---|---|---|
| **High-income economies** | **Upper-middle-income economies** | **Lower-middle-income economies** | **Low-income economies** | **Oil export countries** |
| 34 | 26 | 18 | 10 | 11 |
| Australia | Algeria | Bangladesh | Burkina Faso | Russian Federation |
| Austria | Argentina | Benin | Congo, Dem. Rep. | Azerbaijan |
| Belgium | Azerbaijan | Bolivia | Madagascar | Gabon |
| Bulgaria | Belarus | Cambodia | Mali | Congo, Rep. |
| Canada | Botswana | Congo, Rep. | Niger | Nigeria |
| Chile | Brazil | Egypt, Arab Rep. | Rwanda | Malaysia |
| Czechia | China | Honduras | Sierra Leone | Kazakhstan |
| Denmark | Colombia | India | Sudan | Mexico |

| | | | | |
|---|---|---|---|---|
| Finland | Costa Rica | Kenya | Togo | Algeria |
| France | Dominican Republic | Lebanon | Uganda | Iran, Islamic Rep. |
| Germany | Ecuador | Mauritania | | Sudan |
| Greece | Gabon | Morocco | | |
| Hong Kong SAR, China | Guatemala | Nicaragua | | |
| Hungary | Indonesia | Pakistan | | |
| Ireland | Iran, Islamic Rep. | Philippines | | |
| Israel | Kazakhstan | Senegal | | |
| Italy | Malaysia | Tunisia | | |
| Japan | Mexico | Tanzania | | |
| Korea, Rep. | Namibia | | | |
| Netherlands | North Macedonia | | | |
| New Zealand | Paraguay | | | |
| Norway | Peru | | | |
| Poland | South Africa | | | |
| Portugal | Thailand | | | |
| Romania | Turkiye | | | |

| | | | | |
|---|---|---|---|---|
| Russian Federation | Ukraine | | | |
| Singapore | | | | |
| Slovak Republic | | | | |
| Slovenia | | | | |
| Spain | | | | |
| Sweden | | | | |
| Switzerland | | | | |
| United Kingdom | | | | |
| United States | | | | |