# Impact of Economic Growth and Renewable Energy Consumption on $CO_2$ Emissions: New Evidence for the Top 10 Highest $CO_2$ Emission Countries

Master's Thesis
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Berdasarkan penilaian yang diberikan oleh Tim Penguji, maka tesis tersebut dinyatakan **LULUS**

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## PLAGIARISM-FREE STATEMENT

I hereby declare that in writing this thesis there is no work that has ever been submitted for obtaining a graduate degree at a university, and to the best of my knowledge there is also no work or opinion that has ever been written or published by anyone else, except those that are referred to in writing in this text and is mentioned in the reference. If it is proven in the future that this statement is not true, then I am willing to accept any punishment/sanctions according to the applicable regulations.

Yogyakarta, 27 May 2024

Atif Yaseen

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The author really hopes that this thesis can provide sustainable benefits now and in the future.

Yogyakarta, 27 May 2024

Atif Yaseen

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**Abstract**

This study examines the impact of economic growth and renewable energy consumption on carbon emissions in the highest CO2 emitting countries. To achieve this objective, the study uses a panel annual data of the top 10 ten highest CO2 emitting countries from 1990-2020. This research uses the Environmental Kuznets curve (EKC) hypothesis framework which postulates an inverted U-shaped relationship between pollutant levels and per capita income and employs a pooled mean group autoregressive distributed lag (PMG-ARDL) model.

The research finding confirms the presense of an inverted U-shaped relationship between economic growth and carbon emissions, and is therefore in accordance with the EKZ hypothesis. As a consequence, economic growth tends to increase carbon emissions to a certain limit. When economic growth is very high, estimated in this model at 11%, then carbon emissions can fall. This shows the high costs of reducing carbon emissions. On the other hands, the results show that renewable energy consumption, trade openness, and urbanization have positive effect on CO2 emissions.

This finding is in accordance with the results of robustness tests using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) regression analysis, except for renewable energy which shows a weak relationship in the short and long term. In addition, the PMG-ARDL results confirm that there is adjustment to deviations from long-term equilibrium relatively quickly.

Overall, our findings underscore the importance of policy recommendations aimed at reducing CO2 emissions in these countries. This research contributes to the existing literature by shedding light on the intricate dynamics between economic growth, energy sources, and environmental sustainability.

**Key Words**: Economic growth, Renewable energy, Trade openness, Urbanizations, Carbon emissions, PMG-ARDL

# CHAPTER I

# INTRODUCTION

## 1.1 Background

In recent decades, a significant global economic concern has been the impact of climate change. According to Miralles-Quirós et al., (2022), the main reason for global warming is the use of fossil fuels. The emission of carbon dioxide (CO2) from fossil fuels into the atmosphere, leading to heat retention and global warming, is highlighted by Mathew, (2022); Millar et al., (2018). The burning of fossil fuels is responsible for around 90% of all CO2 emissions worldwide, according to reports from the *Joint Research Centre* (JRC) of the *European Commission* (Olivier et al., 2012; Shayanmehr et al., 2020). Carbon dioxide emissions (CO2) increased by 88% in the last ten years, from 25 million kilotons in 1990 to 40.84 million kilotons in 2020 (World Bank, 2020).

A report from the *Emissions Database for Global Atmospheric Research* (EDGAR, 2023) states, the top 10 countries contributing the most to CO2 emissions, measured in million tons of CO2, are predominantly developed nations, with nine of them belonging to the G20. In 2023, China topped the list, emitting 12,666.43 gigatons, followed by the United States at 4,853.78 gigatons and India at 2,693.03 gigatons (Crippa et al., 2023). To solve the environmental problems caused by carbon emissions, there is an urgent need for international cooperation, as these numbers demonstrate.

The reasons behind carbon dioxide (CO2) emissions vary from one country to another, as each country's unique economic characteristics contribute an essential role in determining its $CO_2$ emissions amount (Disli et al., 2016). These emissions are caused by a number of causes, including as population expansion, globalization, energy consumption, environmental legislation, economic growth, and technological improvements (Bouri et al., 2023; Lee et al., 2022; Li et al., 2023; Ma et al., 2023). According to the findings of Grossman et al., (1991, 1995) the economic performance of a country has major effects on its $CO_2$ emissions. However, the relationship between economic growth and emissions can vary across different countries. Grossman et al., (1991, 1995) research suggests that initially, as the economic growth increases, $CO_2$ emissions tend to rise. However, this trend eventually reverses once the economic growth reaches a higher level. Interestingly, in some countries, economic growth is interlinked with falls in emissions, while in others, economic development results in a rise in $CO_2$ emissions. Saidi et al., (2016) also emphasize that an upsurge in economic growth can result in higher $CO_2$ emissions. This highlights the complexity of the association among economic factors and $CO_2$ emissions, with outcomes varying based on specific country contexts.

In the 1950s, economist Kuznets introduced the Kuznets curve. In the 1990s, Grossman et al., (1991, 1995) delved into the association between environmental pollution and economic growth. They discovered that pollutants such as sulfur dioxide and smog increased with per capita GDP at lower income levels but decreased at higher income levels, forming a curve shaped like an inverted U-shaped. To further establish this idea, panayotou, (1994) formalized the environmental kuzents curve, acknowledging the connection between the envrionment and income. The EKC model depicts an inverted U-shaped relationship between environmental quality and economic growth. It suggests that carbon emissions rise with economic until they reach a "threshold" or "tipping point," after which they start to decline. Over the past two decades, researchers, including Ahmad et al., (2017); Lee, (2019); Wang et al., (2023), have carried out practical investigations on the link between CO2 emissions and economic growth under the EKC hypothesis.

The connection between CO2 emissions and the source of renewable energy is mixed. Many experts agree that employing renewable energy is a viable technique to curb CO2 emissions and align with eco-friendly development objective (Dong et al., 2018). However, some researchers present contrasting views (Bulut, 2017; Chindo et al., 2015; Magazzino, 2014; Saidi et al., 2016) suggesting a direct connection among renewable energy consumption and CO2 emissions. According to the World Bank, (2020), renewable energy accounted for 19.77% of the inclusive final energy consumption. Despite a strong global economy in 2018, resulting in a 2.3% rise in worldwide energy usage, there was a notable 1.7% increase in energy-related CO2 emissions. These emissions reached 33.1 gigatons, surpassing the previous figure of 32.5 gigatons (International Energy Agency (IEA), 2019).

Despite its connection to economic growth, an increase in trade openness has resulted in a significant uptick in CO2 emissions, with carbon emissions contributing to 73% of this increase. Numerous studies have delved into the intricate association between trade openness and CO2 emissions, revealing both direct and indirect effects. Scholars like Ansari et al., (2020); Nasir et al., (2011) argue for a direct association between trade openness and CO2 emissions. However, Managi et al., (2009) suggest that the effect varies among OECD and non-OECD countries, with trade having both positive and negative effects on CO2 emissions, respectively. Conversely, Al-Mulali et al., (2015); Mahmood et a., (2020) present findings that underscore the negative impact of trade openness on $CO_2$ emissions. Unraveling the environmental impact of trade openness entails considering the overall effects of composition, scale, and technology, as discussed by Antweiler et al., (2001); Farhani et al., (2014).

Moreover, when considering the practical aspects, past research has mainly concentrated on a range of factors like economic growth, renewable and non-renewable energy sources, trade openness, and more. These studies have explored how these factors relate to $CO_2$ emissions in various regions and countries. Researchers typically use metrics such as $CO_2$ metric tons or $CO_2$ kilo tons to represent carbon emissions. In assessing economic growth (GDP per capita -constant US$ 2010) has been a common measurement method, as demonstrated in studies conducted by Dauda et al., (2021); Mahmood et al., (2019); Mukhtarov et al., (2022); Naz et al., (2019); Radmehr et al., (2021).

To the best of our knowledge, no one has conducted any empirical studies to investigate how economic growth and the use of renewable energy might affect the amount of $CO_2$ emissions in the top 10 $CO_2$ emitting countries. Our research takes a unique approach to fill in these gaps. Instead of the usual methods, we use different ways to measure $CO_2$ emissions (specifically, consumption-based $CO_2$) based on (Liddle, 2018), and economic growth (annual GDP growth) based on the work of Osobajo et al., (2020). We've chosen the PMG-ARDL estimation method to analyze data from the top 10 highest $CO_2$ emitting countries from 1990 to 2020. This method allows us to look at both short run and long run effects, exploring the possibilty of and association among $CO_2$ emissions and economic growth that resembles and inverted U-shape. While other studies, like the one by Ertugrul et al., (2016), have used the VECM Granger causality method, mainly focusing on individual levels, our research builds on this foundation, using different methods. Additionally, we incorporate the latest reports on the top ten CO2-emitting countries. Our goal with this study is to fill in the gaps in existing research by looking into how economic growth and the use of renewable energy impact CO2 emissions in one of the top ten emitters' countries. The focus on these top ten emitters is particularly interesting because of their significant carbon emissions, developed status, and representation of nine G20 countries.

### 1.2 Problem Statement

The increase in CO2 emissions is a contentious issue in contemporary research, with studies suggesting that developed nations may be primarily responsible for the recent surge. Murshed et al., (2022) underscores the significance of climate change as a substantial environmental challenge, with emissions escalating in developing nations and a significant portion of global emissions attributed to developed countries. The *Emissions Database for Global Atmospheric Research* (EDGAR, 2023) report for 2023 further corroborates this, highlighting that developed nations occupy the top 10 positions for the highest CO2 emissions (Crippa et al., 2023). The escalating concentration of CO2 emissions over recent decades poses a severe threat to environmental sustainability and contributes to the rising global temperatures (Bölük et al., 2014). In light of these concerns, there is a growing consensus that exploring the association between CO2 emissions and trade openness in developed countries is imperative (Dissanayake et al., 2023). Furthermore, there is a call for future researchers to reevaluate the economic impacts of renewable energy, incorporatinf various influencing factors into their analyses.

### 1.3 Research Objective

To investigate the relationship between $CO_2$ emissions, renewable energy, and economic growth over the long run and short run in the top 10 $CO_2$-emitting countries from 1990 to 2020.

### 1.4 Research Question

How do the economic growth and renewable energy affect $CO_2$ emission in the top 10 highest $CO_2$ emitting countries?

### 1.5 Research Contributions

**1.** For the Author's

The author benefits from this research in terms of gaining additional knowledge in environmental economics and the theory of the environmental Kuznets curve in the top 10 $CO_2$ emitter countries. In particular, the author can further explore the potential effects of economic growth, renewable energy, trade openness, and urbanization on $CO_2$ emissions.

**2.** For the Academicians

This research provides both empirical and theoretical benefits, making a significant input to the field of environmental economics. Furthermore, it sheds light on the effect of economic growth and renewable energy on $CO_2$ emissions in the top 10 $CO_2$ emitter countries.

Additionally, it can serve as a reference for other researchers conducting further studies.

**3.** For Stakeholder/Policy Makers

The present study's outcomes are effective for policy makers and stakeholders in developing policies related to reducing carbon emissions. These polices can be beneficial for both society and the global perspective.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Theoretical Background

Several studies have employed the Environmental Kuznets Curve (EKC) hypothesis to investigate the relationship between economic growth and carbon emissions in a growth model (Li et al., 2024; Wang et al., 2024). This section provides the debate on the EKC hypothesis and how it has been used to explain the concepts of economic growth and carbon emissions. Environmental sustainability is a prerequisite for both economic growth and sustainability. As such, the link between environmental quality and economic growth has emerged as a significant subject of research in the modern era (Murshed et al., 2021). The EKC hypothesis, proposed by Grossman et al., (1991), is a widely popular theory that explains the relationship between economic development and environmental pollution from both academic and policy-making standpoints. To explain this idea more clearly, Panayotou in 1994 developed the Environmental Kuznets Curve (EKC), which shows how environmental quality and income levels are related (Panayotou, 1994). The focus of debate and arguments then progressively moved to the EKC. According to certain research, within the framework of this investigation, the findings validate the EKC theory. The effect of economic growth on environmental deterioration first increases as income levels rise, and then shows a declining trend (Wang et al., 2024). Since the EKC hypothesis suggests that economic development would solve environmental issues in the future without the need for government action, testing it becomes more and more crucial. Numerous indicators of environmental deterioration have been examined in relation to the EKC concept including; deforestation (Bhattarai et al., 2001; Bulte et al., 2001; Panayotou, 1994), Carbon emissions (Holtz-Eakin et al, 1995; Timmons Roberts et al, 1997). However, research on the relationship between CO2 emissions and economic growth is inconsistent when compared to other air and water contaminants. Some study indicates a linear correlation between CO2 emissions and per capita income (Shafik, 1994; Shafik et al., 1992), others reported an inverted U-shaped relationship (Apergis et al., 2009; Cole et al., 1997; Lean et al., 2010; Timmons Roberts et al., 1997), or even an N-shaped relationship (Grossman et al., 1995; Shafik, 1994).The conventional EKC is a representation of an economic theory that clarifies the connection between economic growth and environmental pollution. Furthermore, another study, investigated in industrialized nations between 1977 and 2013, revealed that the link between ecological footprint and economic growth has an inverted U-shaped pattern (Destek et al., 2019). Moreover, to examine the connection between economic complexity and CO2 emissions in Portugal, Ireland, Italy, Greece, and Spain using a DOLS estimator, the empirical results suggested they had an inverted U-shaped and further N-shaped connection (Balsalobre-Lorente et al., 2022). The empirical findings demonstrate that income inequality has caused the relationship between economic growth and carbon emissions to shift from an inverted U-shaped relationship to an N-shaped relationship. This implies that income inequality modifies the environmental Kuznets curve and adds complexity to the process of decoupling economic growth and carbon emissions (Wang et al., 2023). Based on the previous study literature, the present study employs the Environmental Kuznets Curve (EKC) theory to test the hypothesis of the research.

Over the past two decades, researchers, including Ahmad et al., (2017); J. W. Lee, (2019), have carried out practical investigations on the link between CO2 emissions and economic development under the EKC concept. According to the EKC, economic expansion puts harmful pressure on the environment; however, at a certain stage of economic development, this pressure is lessened because the nation's income rises as a result of the economic growth (Ahmad et al., 2017; Al-Mulali, Saboori, et al., 2015).

## 2.2 Empirical Background

In recent decades, environmental economics has extensively investigated the essential association between CO2 emissions and economic growth. Earlier studies by Alshehry et al., (2015); Azam et al., (2016); Saboori et al., (2018) indicate a positive correlation between CO2 emissions and economic growth. The increase in CO2 emissions is attributed to human activities related to energy consumption driven by economic development, as noted by Sadorsky, (2010). Numerous studies, including Gao et al., (2014); Mikayilov et al., (2018); Nosheen et al., (2021), indicate that both energy consumption and economic growth contribute progressively to CO2 pollution.

The environmental challenge that countries currently face is to produce energy that is both secure and affordable while concurrently decreasing greenhouse gas emissions, as emphasized by Menyah et al., (2010). Energy usage plays a crucial role in boosting industrial production, serving as a fundamental driver of economic growth (Pirlogea et al., 2012). While there is an urgent need to minimize CO2 emissions resulting from energy usage, it is imperative to achieve this without compromising economic growth and prosperity, as highlighted by Paramati et al., (2021).

Over the past few years, scholars have explored investigations into the environmental Kuznets curve, but the results have varied. For instance, Apergis et al., (2010) investigated the association among CO2 emissions, economic growth, and energy consumption in 11 Commonwealth nations, supporting the validity of the EKC. They found that economic growth could contribute to addressing environmental challenges. On the other hand, Acaravci et al., (2010) determined that the EKC was not confirmed in the majority of 19 European nations when examining the link between energy consumption, economic development, and CO2 emissions. Another study by Saboori et al., (2013) delved into the connection between CO2 emissions, economic growth, and energy consumption for five ASEAN nations: Malaysia, Thailand, Indonesia, the Philippines, and Singapore. Using ARDL, they found a weak (insignificant) relationship supporting the long-term EKC for Thailand and Singapore, with only short-term findings validating the EKC for Thailand.

In terms of renewable energy, BRICS countries play a significant role, contributing 36% to the total global renewable energy output aimed at curbing carbon emissions. There's been a consistent increase in renewable energy projects within these countries (Sebri et al., 2014). Looking at the broader context of climate change, renewable energy sources have long been recognized for their potential to decrease CO2 emissions and foster an eco-friendly environment (Charfeddine et al., 2019). However, it's important to note that some researchers, using the OLS approach, discovered that renewable energy consumption didn't necessarily reduce CO2 emissions in the European (Dogan et al., 2016). According to Al-Mulali et al., (2016), the effect of renewable energy consumption on pollution was explored across various regions. The findings suggested a decrease in pollution in certain areas like

Europe, Asia, and America, while no significant impact was observed in other regions. Bélaïd et al., (2017) investigated the linkage between renewable electricity consumption and $CO_2$ emissions, highlighting its potential for a cleaner environment. However, the research noted that Algeria has not yet reached an optimal level in this regard. Dong et al., (2018) emphasized that renewable energy contributes an important role in reducing $CO_2$ emissions. Additionally, Fan et al., (2023) discovered a one-sided normal association between economic growth and renewable energy consumption in their study.

Numerous studies have explored the connection between $CO_2$ emissions and trade openness, yielding diverse outcomes. The relationship between $CO_2$ emissions and trade openness can be both positive and negative. For instance, research conducted in Pakistan, Italy, Portugal, Romania, Sweden, and 105 other countries revealed a positive correlation between $CO_2$ emissions and trade openness (Shahbaz et al., 2017). Conversely, studies conducted in Denmark, Germany, Spain, and ten newly industrialized countries argued for a negative relationship between $CO_2$ emissions and trade openness (Atici, 2009). Meanwhile, some studies found that trade openness might contribute to increased environmental pollutants in India (Tiwari et al., 2013).

Previous research indicates that the association between $CO_2$ emissions and urbanization is nuanced, with both positive and negative effects. In countries such as Tunisia, Austria, Denmark, Finland, the Netherlands, and Sweden, urbanization development is positively correlated with $CO_2$ emissions (Kasman et al., 2015). Conversely, Greece, Ireland, Italy, Poland, and Romania experience a negative impact, with a 1% increase in urbanization leading to a 1.91% decrease in carbon emissions. This aligns with earlier findings and highlights the potential of modernization to mitigate these effects (Martínez-Zarzoso et al., 2011). Additionally, the impact of urbanization on $CO_2$ emissions varies based on a country's level of development, as indicated by a study by Poumanyvong et al., (2010). A comprehensive investigation involving 147 countries, utilizing the GMM system, found that urbanization contributes to emissions reduction through improved energy efficiency (Liobikienė et al., 2019). On the contrary, Wang et al., (2018) stress that urbanization plays a significant role in driving the excessive growth of $CO_2$ emissions.

**Table 1. Summary of the Literature Review**

| Authors | Data Set | Methods | Findings |
|---|---|---|---|
| **1.** Azam et al., 2016 | China,USA, Japan, India 1971-2013 | Panel cointegration, FMOLS Method | CO2 emissions and energy use have negative impacts, while trade and human capital have positive impacts. CO2 emissions have a beneficial link with economic growth in China, Japan, and the USA, while there is an indirect link in India. |
| **2.** Alshehry et al., 2015 | Saudia Arabia 1971-2010 | Johansen multivariate cointegration Technique | The research indicates a long-run association among energy consumption, energy prices, CO2 emissions, and economic growth, along with a long-run Unidirectional causality from consumption to growth and CO2 emissions, and bidirectional causality from emissions to growth. |
| **3.** Saboori et al., 2018 | China, Japan and South Korea 1980-2013 | Granger causality, Johansen cointegration test,Generalized Impulse Response functions (GIRF) | The research outcomes indicate a unidirectional causality from oil consumption to economic growth in China and Japan, and from oil consumption to CO2 emissions in South Korea. The outcomes of the Granger-Induced Causality Test (GIRF) suggest that economic growth in China and South Korea demonstrates beneficial responses to oil consumption. This variable shows indirect responses to the same shock in Japan. |
| **4.** Zhang et al., 2019 | China 1960-2007 | Multivariate model, Unit root test and casualty test | There is a unidirectional granger flow from economic growth to energy consumption as well as a unidirectional granger from energy use to total CO2 emissions. Research demonstrates that energy use and CO2 emissions do not drive economic development. |
| **5.** Abid, 2015 | Tunisia 1980-2009 | Cointegrated VECM model specification and accounting for structural breaks, | The findings indicate support for the Environmental Kuznets Curve (EKC) theory for greenhouse gas emissions, demonstrating a monotonically growing relationship between total economic growth and CO2 emissions. Granger causality analysis suggests unidirectional causality from formal economic growth to CO2 emissions, and co-integration correlations are present. |
| **6.** Sadorsky, 2010 | 22 emerging countries 1990-2006 | GMM Techniques | The study's findings reveal a statistically significant and favorable connection between energy consumption and financial development. Financial development is assessed using stock market variables such as stock market turnover, capitalization to economic growth, and value trade to economic growth. |
| **7.** Gao et al., 2014 | Sub-Sahara African 1980-2009 | Panel cointegration & Panel- VECM | The research indicates that the long-run use of energy statistically significantly affects CO2 emissions, supporting the inverted U-shaped environmental Kuznets curve hypothesis in SSA regions. The short-run causality is unidirectional, while long-run bidirectional causality is observed. |

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|---|---|---|---|
| **8.** Mikayilov et al., 2018 | Azerbaij n 1992-2013 | Cointegration analysis, Johansen, ARDL, DOLS, FMOLS & CCR methods | The study confirms that economic growth positively impacts long-term emissions in Azerbaijan, contradicting the EKC hypothesis. The income elasticity of CO2 emissions ranges from 0.7% to 0.8%, allowing short-run imbalance adjustments. |
| **9.** Nosheen et al., 2021 | Asian Economies 1995-2017 | Cross-sectional dependence problem & use CADF and CIPS unit root tests. LM bootstrappanel co-integration Test | The DOLS results indicate an inverted u- shaped hypothesis among economic growth and CO2 emissions in Asian economies, with tourism playing a significant role in increasing environmental degradation. Other factors like energy use, urbanization, trade, and financial development also contribute to this degradation. |
| **10.** Menyah et al., 2010 | USA 1960-2007 | Granger causality test | The results of this study indicate a unidirectional causality from nuclear energy use to CO2 emissions without feedback. However, there is no causality from renewable energy to CO2 emissions. The econometric model indicates that nuclear energy use can be useful in reducing CO2 emissions. |
| **11.**Pirlogea et al., 2012 | Span, Romania and European Union 1990-2010 | Testing the stationarity, Testing cointegration, Testing causality for the cointegrated series | The study reveals long-run and short-run relationships among energy use and economic growth in Romania and Spain. Long-run data shows a linkage between energy consumption and petroleum products, while short-run data reveals a unidirectional relationship between renewable energy consumption and economic growth, with natural gas being the only valid direction. |
| **12.**Paramati et al., 2021 | 25 OCED Economies 1991-2016 | CD and CIPS tests, AMG and FMOLS | Green technology, FDI inflows, and trade openness significantly reduce CO2 emissions in OECD economies, with financial deepening and per capita income also contributing positively. |
| **13.**Sebri et al., 2014 | BRICS 1971-2010 | VECM, ARDL | The findings of this study indicate that there exists a long-run relationship between the variables based on the ARDL technique. Meanwhile, the VECM outcomes confirm bidirectional Granger causality between economic growth and renewable energy use. |
| **14.**Charfeffin et al., 2019 | MENE Region 1980-2015 | PVAR | The study indicates that while renewable energy use and financial development assert a slight effect on CO2 emissions and economic growth, they are still weak in contributing to environments. |

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|---|---|---|---|
| **15.**Dogan et al., 2016 | European union 1980-2012 | Cross-sectional dependence and using the DOLS estimator | The Dumitrescu-Hurlin non-causality approach and research on renewable energy and trade both support the Environmental Kuznets Curve (EKC) hypothesis. They demonstrate a unidirectional causality from trade openness to CO2 emissions, from CO2 emissions to nonrenewable energy, and from renewable energy to carbon emissions. Furthermore, there is bidirectional causality between renewable energy and carbon emissions. |
| **16.** Al-Mulali et al., 2016 | 27 Advanced Economics 1990-2012 | Panel cointegration, FMOLS and the VECM | The results show that variables are integrated, and study results indicate that economic growth, NR, and UR increase CO2 emissions. However, RE, TD, and PC decreased. Therefore, the existence of the inverted U-shaped association between economic growth and CO2 emissions was validated, signifying the support for the EKC hypothesis. |
| **17.** Bélaïd et al., 2017 | Algeria 1980-2012 | ARDL | The long-term cointegration connection between the variables is confirmed by the empirical findings. While the utilization of renewable energy sources improves environmental quality, economic expansion and non-renewable power use have the opposite effect. Short-term data indicate that economic growth has an impact on power usage, supporting the conservation theory. |
| **18.**Dong et al., 2018 | China 1965-2016 | ARDL | The research validates the EKC for China's CO2 emissions. Utilizing renewable energy sources and natural gas together can reduce CO2 emissions. Natural gas has a diminishing mitigating impact over time. The importance of renewable energy will grow over time. |
| **19.**Fan et al., 2023 | 31 Chinese Provinces 2005-2015 | Unit root test, cointegration test,VECM, Impulse response function analysis, and Granger causality | According to the empirical findings, economic growth, FDI per capita, and REC per capita have a long-term, stable equilibrium connection to one another. Although targeted FDI combined with a little slowdown in economic growth would provide a major boost to RE in China, FDI cannot, in the medium term, drastically alter REC. |
| **20.** Apergis et al., 2023 | OECD Countries 1985-2020 | Panel cointegration and ECM | With the corresponding coefficients being positive and statistically significant, the heterogeneous panel cointegration test shows a long-run equilibrium link between economic growth, renewable energy consumption, real gross fixed capital creation, and the labor force. The findings of the Granger causality analysis show that there is a short- and long-term bidirectional causal relationship between the use of renewable energy and economic development. |

| | | | |
|---|---|---|---|
| **21.**Nasir et al., 2011 | Pakistan 1972-2008 | Johansen method of cointegration | The Environmental Kuznets Curve is supported by the existence of a quadratic long-run connection between carbon emissions. Positive impacts on emissions are seen for FT and EC. However, the short-term outcomes have refuted the Environmental Kuznets Curve's reality. Since none of the long-run factors influencing emissions are substantial, the short-run results differ from those found in the body of current literature. |
| **22.**Atici, 2009 | Central and Eastern European Countries 1980-2002 | FEM or REM | The findings support the presence of an EKC for this region, according to which per capita CO2 emissions gradually decline as economic growth rises. The region's pollution is mostly caused by the amount of energy used per person, which suggests that the area generates ecologically dirty energy. The trade openness variable suggests that regional emissions have not decreased as a result of globalization. |
| **23.**Shahbaz et al., 2017 | 105 Countries 1980-2014 | Panel cointegration, VECM and FMOLS | Environmental quality is negatively impacted by trade openness for the global, high-income, medium-income, and low- income panels, albeit the effects differ within these various country groups. The panel VECM causality results show a positive feedback relationship between trade openness and carbon emissions in middle-income and globalized economies, whereas trade openness is a cause of CO2 emissions in high- and low-income nations. |
| **24.** Tiwari et al., 2013 | Indonesia 1975Q1 – 2014 Q4 | ARDL, VECM | The cointegration of the variables is confirmed by our findings, indicating the presence of structural breakdowns in the long-term connection. According to the empirical data, trade openness and financial development reduce CO2 emissions, whereas energy use and economic expansion raise it. The energy consumption and CO2 emissions feedback hypothesis has been demonstrated by the VECM causality analysis. Additionally, there is a bidirectional causal relationship between CO2 emissions and economic growth. CO2 emissions are caused by financial development Granger. |
| **25.** Kasman et al., 2015 | New EU Members 1992-2010 | ARDL,VECM Panel unit root tests, panel cointegration methods and panel causality | The Environmental Kuznets Curve hypothesis supports an inverted U-shaped relationship between environment and income in sampled countries. Short-run causality runs from energy consumption, trade openness, and urbanization to carbon emissions, economic growth, energy consumption, and trade openness. Long-run causality coefficients are significant, suggesting these variables may play a crucial role in adjustment. |
| **26.**Martines-Zarzoso et al., 2011 | Developing Countries 1975-2003 | STIRPAT model | The research indicates an inverted U- shaped association among urbanization and CO2 emissions, with positive elasticity for low urbanization levels. Three countries have different impacts, with two having negative emission-urbanization elasticity and the third involving population and affluence. |
| **27.** Poumanyvong et al., 2010 | 99 Countries 1975-2005 | STIRPAT Model | According to the findings, there are differences in how urbanization affects energy usage and emissions depending on the stage of development. Remarkably, urbanization raises energy consumption in the middle-class and upper-class segments while decreasing it in the low-income category. All income levels are benefiting from urbanization's good influence on emissions, although middle-class people experience this effect more than other income groups do. |

| | | | |
|---|---|---|---|
| **28.**Liobikienė et al., 2019 | 147 COUNTRIES 1990-2012 | GMM Model | According to the study's findings, energy efficiencygains from urbanization contribute to emissions reductions. |
| **29.**Wang et al., 2018 | China and India 1980-2014 | Tapio decoupling mode | The main contributors to China's limited decoupling of economic development from carbon emissions are carbon emission intensity, economic growth, urbanization, and industrialization. India is largely decoupling from emissions due to its economic growth and urbanization, indicating that improving energy efficiency is the best course of action for emission-free economic growth. |

Source: Author

The present study investigates the effect of economic growth and renewable energy on CO2 emissions. Previous literature indicates that no study has been conducted on the impact of economic growth and renewable energy on CO2 emissions (consumption- based) in the top 10 CO2-emitting countries. Due to the limitations of previous studies, the present study aims to fill the gap.

Based on the theoretical framework, literature review and gap research found above, the research proposes a hypothesis according to the EKC theoretical framework, namely:

**H1:** There is an EKC inverted U-shaped relationship between economic growth and CO2 emissions.

# CHAPTER III

# RESEARCH METHODS

## 3.1 Research Design

The principal objective of this study is to examine the influence of economic growth and renewable energy sources on CO2 emissions. Employing a quantitative research approach, this investigation utilizes secondary data obtained from the World Bank Indicators and the Global Carbon Atlas. The data analysis employs the PMG-ARDL model for comprehensive examination and interpretation.

## 3.2 Data

The present study aims to investigate the effect of economic growth and renewable energy consumption on carbon dioxide emissions over the period 1990-2020 in the top 10 countries with the highest CO2 emitters (China, United States, India, Russia, Japan, Iran, Germany, South Korea, Saudi Arabia, and Indonesia). In the present research analysis, carbon emissions are measured consumption based. In contrast, economic growth is measured as GDP growth (annual), renewable energy consumption (% of total final energy), and trade openness as the total sum of export and import % of GDP. However, urbanization is measured as the urban population (% of the total population). The data was retrieved from the *Global Carbon Atlas* and World Development Indicators. CO2 emission is the main dependent variables of this research, economic growth and renewable energy is primary independent variable and trade openness and urbanization control variables.

## 3.3 Research Variables

These variables are used for different reasons, such as: In recent studies, some researchers have used consumption-based CO2 emissions (Mukhtarov et al., 2022). The main benefit of considering consumption-based CO2 emissions as a measure of carbon dioxide emissions is that it accounts for emissions not only from final consumption but also from purchases abroad (Hasanov et al., 2021). It has been modified to take into consideration global trade, making it easy to identify carbon emissions generated in one nation and consumed in another (Peters et al., 2012). Many studies use economic growth as a proxy for economic activity (Charfeddine et al., 2020). However, according to some researchers, carbon emissions may play a significant role in economic expansion (Adewuyi et al., 2017; Ghosh, 2010). Kaygusuz et al., (2007) argue that renewable energy will not only address the limitations associated with current energy consumption patterns and provide much-needed modernization of the energy sector but also promote sustainable development objectives. International trade openness significantly contributes to carbon dioxide emissions, while urban populations significantly contribute to these emissions (Khoshnevis Yazdi et al., 2019). The present research examines the effect of economic growth and renewable energy consumption on carbon emissions.

**Table 2. Variable and Source**

| **Variables** | **Measurements** | **Source** |
|---|---|---|
| Carbon emissions ($CO_2$) | Million tons | GCA |
| Economic growth | GDP growth Annual (%) | WDI |
| Renewable energy consumption | % of total final energy consumption | WDI |
| Trade openness | Total sum export and import (% of GDP) | WDI |
| Urbanization | % of total Urban population | WDI |

### 3.4 Theoretical Framework for EKC

The present research investigates, within the context of the Environmental Kuznets Curve theory, the effect of economic growth on the carbon emissions of the top 10 $CO_2$-emitting countries. This research utilized the equations outlined by

Adedoyin et al., (2021); Chu, (2021); Doğan et al., (2019); Nyeadi, (2023); Swart et al., (2020); Taghvaee et al., (2022); Yilanci et al., (2020) , as in Eqs. 1 to 2.

$$CO_{2it} = C_{1it} + \alpha_1 EG_{it} + \alpha_2 EG_{it}^2 + \varepsilon_{it} \qquad (1)$$

The variable in this equation is CO2 (consumption-based carbon emissions). C (intercept); EG (economic growth); $t$ (time period), $\varepsilon$ (error term); and the subscript $i$ and $t$ (country and year); $\alpha$ and $\beta$ (coefficient) in this equation model. The hypothesis of the Environmental Kuznets Curve is validate / confirmed $\alpha1$ (or $\beta1$) and $\alpha2$ (or $\beta2$) are statistically significant and, positive (or negative), respectively. Eq. 2 converts CO2 into natural logarithm form in accordance with (Neagu, 2019; Taghvaee et al., 2022), because increases in CO2 emissions are significantly larger than changes in EG. The given equations are linear in parameters but non-linear in variables due to the presence of the $(EG)it$^2 term. Therefore, when comparing Eqs. 1 to Eq. 2, the latter is less accurate in determining the relationship between CO2 emissions and EG:

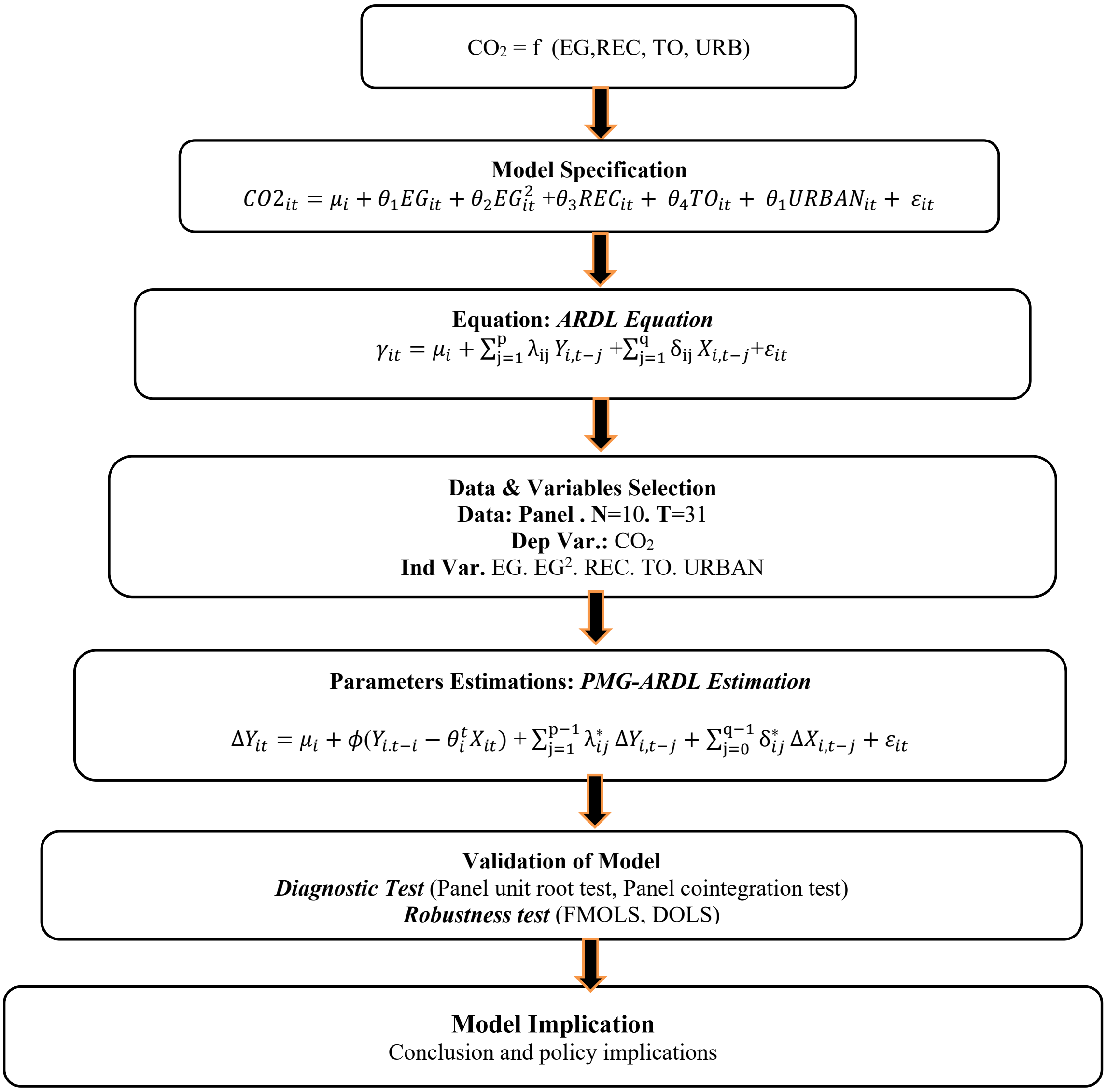
$$lnCO_{2it} = C_{2it} + \theta_1 EG_{it} + \theta_2 EG_{it}^2 + \varepsilon_{it} \qquad (2)$$

### 3.5 Emprical Framework of Research

#### 3.5.1 Cross Section Dependence Test

Before employing the PMG-ARDL test, it's essential to undergo a preliminary examination involving Cross Section Dependence and panel stationarity tests. This testing approach aligns with the methodology outlined by Zhou et al., (2023). In the modern era, interconnected global landscape, various factors can heighten a country's reliance on other global economies. This means that a change in a single variable in one region can impact another economy or region. Failing to account for cross-sectional dependence in panel data might lead to confusing and inaccuarte conclusions. To address this concern, the current study employs threee estimators to identify cross-sectional dependence in the panel of the top 10 CO2-emitting countries. Specifically, the study utilizes the Breusch-Pagan LM test, Pesaran scaled Lagrange Multiplier (LM), and the Pesaran Cross-Sectional Dependence (CD) test. It's important to note that all these tests assume the cross-sectional independence of the panel.

**Figure 1. Research Steps and Framework**



### 3.5.2 Panel Unit Root Test

Another preliminary assessment involves conducting a stationarity test. In the presence of certain conditions, the PMG-ARDL method is applied. The first scenario occurs when all variables are stationary at the level, the second scenario is when all variables are stationary at the 1st difference, and the third scenario is when all variables are stationary both at the level and 1st difference. However, PMG-ARDL cannot be applied if any variables are stationary at the 2nd difference. It's important to note that unit root tests are employed to prevent spurious regression (Androniceanu et al., 2023).To perform these tests, various first-generation unit root tests are utilized, assuming cross-sectional independence. These tests include the Levin, Lin, and Chu test, I'm, Pesaran, and Shin test, as well as Fisher-type tests like ADF-Fisher and PP-Fisher, which were developed by Choi, (2001); Maddala et al., (1999). The Levin, Lin, and Chu test, also known as the LLC test, is a common unit root test, characterized by the limited explanatory power of each unit root test. The other three tests (Im, Pesaran, and Shin test, ADF-Fisher, and PP-Fisher) assume an individual unit root test.

### 3.5.3 Panel Cointegration Test

The cointegration test serves as a crucial tool for examining the enduring connection among multiple variables. Our aim is to discern whether a sustained link exists between the variables under consideration, employing a panel cointegration test. In particular, the cointegration test is utilized to investigate the long-term relationship between the independent and dependent variables. Prior to determining the outcomes of the cointegration test, we conducted panel unit root tests. Thus, the Kao cointegration test was chosen to investigate the cointegration among the variables in the analysis. The Pedroni cointegration test is used for robustness to confirm the Kao cointegration test results.

### 3.5.4 Estimation Using PMG-ARDL

We employed the Pooled Mean Group Auto Regressive Distributed Lag (PMG-ARDL) method to explore the Short run and long run association and used a Robustness Check test for the validation model. For different reasons, we use PMG-ARDL for this study. Meanwhile, ARDL models are often used to analyze dynamic relationships with time series data in a single-equation framework, PMG-ARDL are used to analyze panel or longitudinal data. The current value of the dependent variable is allowed to depend on its own past realizations – the autoregressive part – as well as current and past values of additional explanatory variables – the distributed lag part.

The present research made use of the Panel Mean Group Autoregressive Distributed Lags (PMG-ARDL) model proposed by Pesaran et al., (1999). This model employs three scenarios: a) If all variables are stationary at the level. b) If all variables are stationary in the 1st difference. c) If all variables are a mix of level and 1st difference. Furthermore, the main advantage of the PMG-ARDL model is its ability to examine short- run and long-run effects between variables. The primary benefit of this model, making it superior to other models, is its ability to reduce the problems of endogeneity, heteroscedasticity, autocorrelation, and multicollinearity in models (Nyeadi, 2023). Another reason is that the PMG is favored becasue it allows group-to-group felaxibility and unlimted short-term reactions while enforcing long-term limits by compiling distinct groupings. To clarify, the likelihood-based PMG estimator ensures that the long-run elasticity is constant across all panels, producing reliable and effective estimates only in cases when the homogeneity limitation is verified (Isiksal et al., 2022).

The estimation of the model proceeds as follows: (i) A cross-sectional dependence test (CD) is performed to verify whether there is cross-sectional dependence across the panel; (ii) A panel unit root test (including Levin-Lin-Chao, Im, Pesaran, Shin, ADF, and Phillips-Perron tests); (iii) The Kao cointegration test is implemented to verify the long-run relationship between the variables; (iv) A PMG (pooled mean group estimation) estimation is employed to examine the short-run and long-run relationships between the variables and the speed of adjustment of the short-run disequilibrium towards the long-run equilibrium; and (v) A SUR is estimated to check the robustness of the PMG results. Our study investigation focuses on the ten highest CO2 emissions countries with identical long- term dynamics. The main function is as follows**:**

$$lnCO2 \; = \; f\,(EG, REC, TO, URBAN) \qquad \text{..................} \; (3)$$

Where in this equation $CO_2$ Consumption based CO2 emissions, EG represents the Economic growth, REC represents the Renewable energy consumption, TO represents the trade openness and URB represents the Urbanization. Suppose that the long run relationship between CO2 and its predictors is given by:

$$lnCO2_{it} = \mu_i + \theta_1 EG_{it} + \theta_2 EG_{it}^2 + \theta_3 REC_{it} + \theta_4 TO_{it} + \theta_5 URBAN_{it} + \varepsilon_{it} \text{..........}(4)$$

Where μi is the fixed effects, I = 1, 2, …., N and t = 1, 2, …., T

Because we assume there is endogeneity or the relationship between $(CO2_t - CO2_{t-i})$ therefore a dynamic model should be applied. Pesaran et al., (1999) suggest nesting equation in a general ARDL specification to allow for rich dynamics.

The ARDL (p, q, q, …, q) model can be written as:

$$Y_{it} = \mu_i + \Sigma_{j=1}^{p} \lambda_{ij} Y_{i,t-j} + \Sigma_{j=1}^{q} \delta_{ij} X_{i,t-j} + \varepsilon_{it} \qquad \dots (5)$$

Where $Xij$ are the vector of explanatory variables for group $i$ including the variable of interest (EG and REC) and control variables (TO and URBAN);$\lambda ij$ to represents coefficient of lagged dependent variables and $\delta ij$ are coefficient vectors. The ADRL order must be chosen to ensure the residual of the error correction model is exogenous and serially uncorrelated. By re-parametrization ($i.\ e.\ Yt - Yt - i$), Equation (5) can be written as an error correction form (Zare et al., 2013): Error Correction Model:

$$\Delta Y_{it} = \mu_i + \phi_i Y_{i,t-i} + \beta_i' X_{it} + \Sigma_{j=1}^{p-1} \lambda_{ij}^* \Delta Y_{i,t-j} + \Sigma_{j=0}^{q-1} \delta_{ij}^* \Delta X_{i,t-j} + \varepsilon_{it} \ldots\ldots (6)$$

Where $\theta_i = -\left(1 - \Sigma_{j=1}^{p} \lambda_{ij}\right), \beta_i = \Sigma_{j=0}^{q} \delta_{ij}, \lambda_{ij}^* = -\Sigma_{m=j+1}^{p} \lambda_{im}\ and\ \delta_{ij}^* = -\Sigma_{m=j+1}^{q} \delta_{im}$

By further grouping the variables in level, equation (6) can be rewritten as PMG-ARDL equation:

$$\Delta Y_{it} = \mu_i + \phi_i (Y_{i,t-i} - \theta_i^t X_{it}) + \Sigma_{j=1}^{p-1} \lambda_{ij}^* \Delta Y_{i,t-j} + \Sigma_{j=0}^{q-1} \delta_{ij}^* \Delta X_{i,t-j} + \varepsilon_{it} \quad \ldots\ldots (7)$$

Where $\theta_i = -(\frac{\beta_i}{\phi_i})$ ensures the long-run equilibrium relationship among *Yit* dan
25
*Xit*. The Short run coefficient relating $Yit$ and $Xit$ is defined by $\lambda_{ij}^*$ and $\delta_{ij}^*$. Moreover, $\phi_i$ measures the speed of adjustment of *Yit* toward its long-run equilibrium following a change in $Xit$. If $\phi_i < 0$ ensures that such as long-run relationship exists. Accordingly, discovery of a significantly negative $\phi_i$ can be treated as evidence supporting cointegration between $Yit$ and $Xit$. If $\phi_i < 0$ ensures that such as long-run relationship exists. Accordingly, discovery of a significantly negative $\phi_i$ can be treated as evidence supporting cointegration between $Yit$ and $Xit$.Furthermore, Pesaran and Smith, (1995) show that if the long-run homogeneity constraints—which call for the long-run parameters to be the same across countries—are valid, the PMG estimator

will be more accurate than the mean group (MG) estimator. Consequently, the Hausmann test of the form maybe used to group (MG) estimator. Consequently, the Hausmann test of the form maybe used to confirm the null hypothesis of the long-run homogeneity. Therefore, the null hypothesis of the long run homogeneity can be verified with the Hausmann test of the form $\theta i = \theta i$, $i = 1,2, \ldots, N$

### 3.5.5 Robustness Check

To investigate the robustness of the test, a previous study used fully modified least squares (FMOLS) and dynamic least squares (DOLS) as robustness tests (Naimoglu, 2023). The main advantage of robustness test is to increase the reliability of the results of PMG-ARDL outcomes. DOLS is an efficient estimator if the variables have different degrees of stationarity. In addition, another reason for using the DOLS estimator is that it can consider the internality problem. It can also give effective results for the study data. DOLS not only resolves endogeneity but also corrects serial correlation through different antecedents. When dealing with mixed panel data that show long-term relationships, the FMOLS estimator is often the best choice for checking robustness (Pedroni, 2000). There are some reason for picking this estimator. It's reliable because it's unbiased and efficient in the long run.

# CHAPTER IV
# DATA ANALYSIS AND DISCUSSION

## 4.1. Descriptive Analysis on CO2 Emissions in the Top 10 Highest CO2 Emitters Countries

Table 3 shows the detailed summary of variables in each country used in this study and how they affect each other, such as carbon emissions, economic growth, renewable energy, trade openness, and urbanization. The present research consists of examining the highest emitting countries. The USA, Germany, Japan, and South Korea are developed countries, while China, India, Iran, Indonesia, Russia, and Saudi Arabia are developing countries. In the last 30 years, trends show that in China, carbon emissions and economic growth have increased, with the highest average in the past 30 years being 6353.76 mt and 9.11, respectively. In China, during the same period, both have increased, while the lowest average of carbon emissions and economic growth is in Indonesia, at 374.79 mt and 4.71. However, during the same period, some countries have a high average of carbon emissions, but a low average of economic growth compared to other countries. For example, in the USA, the average carbon emissions are high at 5571.97mt, but the average economic growth is only 2.30. In India, the average carbon emission value is 1413.21mt, and the average economic growth value is 5.84. In India, the average carbon emissions value is lower than America's, but the average value of economic growth is higher. China has the highest average carbon emissions (6353.76 million tons consumption), ranging from 2484.86 to 10914.01, and the standard deviation value is 3054.93. Meanwhile, Indonesia has the lowest average (374.79 million tons consumption), with a standard deviation value of 140.55 and a range from 155.08

to 650.91. Economic growth has the highest average value (9.11) in China; the standard deviation value is 2.78, and it ranges from 2.24 to 14.23. On the other hand, Russia has the lowest average value (0.75), ranging from -14.53 to 10, with a standard deviation of 6.25. India has the highest share of renewable energy use (42.30% of total final energy consumption). The least and most extreme values were documented as 32.57 and 52.95, and the standard deviation is 7.05. In contrast, Saudi Arabia's average value is the lowest (0.016% of total final energy consumption), with a standard deviation value of 0.012, and the least and extreme values were documented as 0.01 to 0.06. Saudi Arabia has the highest trade average value (71.74% of share GDP), with a standard deviation value of 11.75 and the least and extreme value ranging from 49.71 to 96.10. Meanwhile, the USA has the lowest trade openness average value (25.06% of share GDP), with the lowest and extreme values ranging from 19.79 to 30.84, and the standard deviation value is 3.42. Saudi Arabia has the lowest average urbanization value (20 million), with the least and extreme value ranging from 12 million to 30 million, and a standard deviation of 5 million. Conversely, China has the highest average urbanization value (565 million), with a standard deviation value of 1 million, and the least and extreme value ranging from 3 million to 8 million.

**Table 3. Descriptive Statistics Analysis**

**a) China**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 6353.76 | 9.11 | 21.18 | 41.61 | 565 M |
| **Median** | 5882.14 | 9.24 | 17.44 | 38.53 | 554 M |
| **Maximum** | 10914.01 | 14.23 | 33.91 | 64.48 | 867 M |
| **Minimum** | 2484.86 | 2.24 | 11.34 | 22.20 | 300 M |
| **Std. Dev.** | 3054.93 | 2.78 | 8.55 | 11.53 | 177 M |

Source: Author calculation

**b) USA**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 5571.97 | 2.30 | 6.69 | 25.06 | 235 M |
| **Median** | 5528.68 | 2.68 | 5.84 | 24.76 | 236 M |
| **Maximum** | 6132.18 | 4.79 | 11.16 | 30.84 | 274 M |
| **Minimum** | 4714.63 | -2.77 | 4.09 | 19.79 | 188 M |
| **Std. Dev.** | 364.89 | 1.78 | 2.22 | 3.42 | 25 M |

Source: Author calculation

c) **India**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 1413.21 | 5.84 | 42.31 | 35.41 | 343 M |
| **Median** | 1185.67 | 6.45 | 44.16 | 37.80 | 338 M |
| **Maximum** | 2612.89 | 8.85 | 52.95 | 55.79 | 488 M |
| **Minimum** | 577.10 | -5.83 | 32.57 | 15.51 | 222 M |
| **Std. Dev.** | 662.71 | 2.87 | 7.05 | 12.78 | 80 M |

Source: Author calculation

d) **Russia**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 1675.86 | 0.75 | 3.54 | 53.77 | 107 M |
| **Median** | 1632.93 | 1.83 | 3.58 | 50/95 | 107 M |
| **Maximum** | 2536.29 | 10 | 4.04 | 110.6 | 109 M |
| **Minimum** | 1465.25 | -14.5 | 3.18 | 26.26 | 105 M |
| **Std. Dev.** | 238.05 | 6.25 | 0.25 | 13.68 | 1 M |

Source: Author calculation

e) **Japan**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 1224.62 | 0.89 | 4.76 | 25.62 | 108 M |
| **Median** | 1238.95 | 1.08 | 4.34 | 24.39 | 110 M |
| **Maximum** | 1315.19 | 4.84 | 8.45 | 37.43 | 116 M |
| **Minimum** | 1039.80 | -5.69 | 3.34 | 15.72 | 95 M |
| **Std. Dev.** | 62.83 | 2.14 | 1.33 | 7.36 | 8 M |

Source: Author calculation

f) **Iran**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 455.68 | 3.36 | 0.98 | 43.77 | 48 M |
| **Median** | 462 | 2.76 | 0.98 | 43.81 | 47 M |
| **Maximum** | 710.21 | 13.59 | 1.53 | 58.57 | 66 M |
| **Minimum** | 209.94 | -3.74 | 0.44 | 29.23 | 31 M |
| **Std. Dev.** | 163.16 | 4.33 | 0.27 | 6.70 | 10 M |

Source: Author calculation

g) **Germany**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 867.80 | 1.46 | 8.27 | 67.60 | 61 M |
| **Median** | 877.50 | 1.68 | 7.28 | 70.92 | 62 M |
| **Maximum** | 1054.74 | 5.26 | 18.60 | 88.52 | 64 M |
| **Minimum** | 647.25 | -5.69 | 1.99 | 40.58 | 58 M |
| **Std. Dev.** | 88.15 | 2.25 | 5.52 | 17.06 | 1 M |

Source: Author calculation

h) **South Korea**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 498.17 | 4.99 | 1.42 | 70.74 | 38 M |
| **Median** | 498.69 | 4.85 | 0.96 | 69.03 | 39 M |
| **Maximum** | 670.17 | 11.47 | 3.63 | 105.6 | 42 M |
| **Minimum** | 250.51 | -5.13 | 0.44 | 46.92 | 31 M |
| **Std. Dev.** | 122.93 | 3.57 | 0.95 | 17.07 | 3 M |

Source: Author calculation

i) **Saudia Arabia**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 429.70 | 3.42 | 0.06 | 71.74 | 20 M |
| **Median** | 401.01 | 2.78 | 0.01 | 69.50 | 19 M |
| **Maximum** | 707.13 | 15.19 | 0.06 | 96.10 | 30 M |
| **Minimum** | 208.50 | -4.34 | 0.01 | 49.71 | 13 M |
| **Std. Dev.** | 162.35 | 4.87 | 0.01 | 11.75 | 5 M |

Source: Author calculation

**j) Indonesia**

| Stat./Variables | MTCO2 | EG | REC | TO | URB |
|---|---|---|---|---|---|
| **Mean** | 374.79 | 4.71 | 40.26 | 53.47 | 105 M |
| **Median** | 346.63 | 5.17 | 41.46 | 52.89 | 105 M |
| **Maximum** | 650.91 | 8.22 | 59.18 | 96.19 | 154 M |
| **Minimum** | 155.08 | -13.1 | 19.77 | 32.93 | 55 M |
| **Std. Dev.** | 140.56 | 3.83 | 11.40 | 11.10 | 30 M |

Source: Author calculation

## 4.2 Estimation of the Relationship Between CO2 Emissions and Economic Growth and Renewable Energy Consumption

### 4.2.1 Cross Section Dependence Test

This study examines cross-sectional dependence by conducting three tests, namely the Breusch and Pagan LM test, Pesaran scaled LM test, and Pesaran CD test. The results of these tests are presented in Table 4. The findings suggest that the statistical values for the three cross-section dependencies are insignificant at a different level. In simpler terms, all the tests confirm the existence of cross-sectional dependence in the panel of the top 10 CO2 emitters countries for the variables under consideration.

**Table 4. Cross-Section Dependence Test**

| Test | Statistic | Prob. | Conclusion |
|---|---|---|---|
| Breusch-Pagan LM | 52.3989 | 0.2089 | Accept |
| Pesaran scaled LM | 0.7799 | 0.4354 | Accept |
| Pesaran CD | 0.4255 | 0.6705 | Accept |

Source: Author calculation

### 4.2.2 Panel Unit Root Test

After explaining the cross-section dependence test, the study conducted Levin, Liu & Chu, Im, Pesaran and Shin, ADF Fisher chi-square, and PP-Fisher chi-square tests to check for the presence of the unit root in the variables. The results are presented in Table 5. The outcomes of the present study indicate that variables are stationary at the level and 1st difference. The variable MtCO2 is stationary at the level and 1st difference. GDP is stationary at the level and 1st difference in all tests, while REC, TO, and URB are stationary at the level and 1st difference.

**Table 5. Panel Unit Root Test**

**At Level Unit Root Test (Individual Intercept)**

| Test | LnMtCO2 | GDP | REC | TO | URB |
|---|---|---|---|---|---|
| Levin, Liu & Chu | -2.62(0.0043) | -3.37(0.0001) | 1.74(0.9592) | -1.37(0.0859) | -2.67(0.0038) |
| Im, Pesaran, and Shin | -0.27(0.3923) | -6.42(0.0000) | -4.44(1.0000) | -1.15(0.1253) | -0.49(0.3138) |
| ADF-Fisher Chi-square | 33.59(0.0290) | 84.55(0.0000) | 10.59(0.9591) | 28.72(0.0935) | 40.89(0.0039) |
| PP-Fisher Chi-square | 52.80(0.0001) | 90.59(0.0000) | 10.35(0.9414) | 30.73(0.0588) | 53.78(0.0001) |

Source: Author calculation

**At 1st Difference Unit Root Test (Individual Intercept)**

| Test | LnMtCO2 | GDP | REC | TO | URB |
|---|---|---|---|---|---|
| Levin, Liu & Chu | -3.30(0.0005) | -7.54(0.0000) | -2.02(0.0217) | -13.78(0.0000) | -1.38(0.0840) |
| Im, Pesaran, and Shin | -5.62(0.0000) | -12.84(0.0000) | -5.54(0.0000) | -11.88(0.0000) | -1.67(0.0474) |
| ADF-Fisher Chi-square | 71.95(0.0000) | 170.56(0.0000) | 78.32(0.0000) | 120.84(0.0000) | 28.87(0.0904) |
| PP-Fisher Chi-square | 131.10(0.0000) | 270.71(0.0000) | 139.43(0.0000) | 182.69(0.0000) | 29.15(0.0848) |

Source: Author calculation

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### 4.2.3 Panel Cointegration Test

The findings of the Kao and Pedroni cointegration test are reported in Table 6 (a & b). The panel kao cointegration test indicates a long-term relationship between the variables. The findings indicate that there is a connection among the independent and dependent variables among the top 10 CO2 emitters countries. Furthermore, based on the study findings, the probability value obtained from the cointegration test is less than the chosen significance level (10%). The results provide evidence to show a cointegration relationship among the variables. If the variables are cointegrated, it means a long-term relationship exists, and we proceed further for analysis; vice versa.

**Table 6 a. Kao Panel Cointegration Test**

| Test | Statistics | Value | Significance |
|---|---|---|---|
| Kao cointegration test | ADF | -1.4849 | 0.0688 |

Source: Author calculation

The results of the Pedroni panel cointegration test are presented in Table 6 b. The outcomes of the Pedroni panel cointegration test show that cointegration exists between the variables. The validity of the Kao cointegration test was also confirmed by Pedroni cointegration tests.

**Table 6 b. Pedroni Panel Cointegration Test**

| Test | Statistics | Prob. | Statistics | Prob |
|---|---|---|---|---|
| Panel v-Statistics | -4.3894 | 1.0000 | -5.6299 | 1.0000 |
| Panel rho-Statistics | 4.4629 | 1.0000 | 4.5931 | 1.0000 |
| Panel PP-Statistics | -1.2839 | 0.0996 | -6.0139 | 0.0000 |
| Panel ADF-Statistics | 2.2764 | 0.0114 | -3.4615 | 0.0003 |
| Group rho-Statistics | 5.6431 | 1.0000 | | |
| Group PP-Statistics | -8.8847 | 0.0000 | | |
| Group ADF-Statistics | -3.9450 | 0.0000 | | |

Source: Author calculation

### 4.2.4 Long run and Short Run Results

Table 7 shows the outcomes of the PMG-ARDL model. Based on the long-run outcomes of the PMG-ARDL model, the variables of economic growth, renewable energy consumption, trade openness, and urbanization contribute to the rise in CO2 emissions. This implies that these variables have a positive effect on CO2 emissions. Furthermore, in the panel data investigations, in the long run, the value of EG (0.50) is high, followed by renewable energy consumption (0.14), trade openness (0.03), and urbanization (0.00000). However, the negative sign should indicate that CO2 emissions rise in tandem with economic growth, but that CO2 emissions fall after economic growth reaches a particular level. This demonstrates that the effect of rising CO2 emissions is due to economic growth rather than economic size. The value of the square economic growth in the PMG-ARDL model's long-run outcome is high compared to the short-run outcomes of the model. Likewise, the speed of adjustment, which indicates the change from the short run to the long run in the model, is identified by the error correction term (ECT-1). If the p-value of the error correction term is statistically significant and negative, that means the model is stable and at a balanced position. In the short run, PMG-ARDL outcomes indicate that economic growth, renewable energy consumption, trade openness, and urbanization significantly affect CO2 emissions. Nevertheless, in the short-run outcomes of the PMG-ARDL model, the value of the variable 'urbanization' (2.30) is high, followed by renewable energy consumption (0.03), economic growth (0.003), and trade openness (0.001). Similarly, the square of EG negatively affects CO2 emissions in the short run according to the PMG-ARDL estimation, and the value of the square of EG is (-0.0004). The study results confirm the environmental Kuznets curve in the top 10 CO2 emitters countries.

**Table 7. Long Run and Short Run Results**

| Variable | Coefficient | Std. Error | t-Statistic | Prob.* |
|---|---|---|---|---|
| | **Long Run** | | | |
| EG | 0.506835 | 0.125068 | 4.052473 | 0.0001 |
| EG2 | -0.022816 | 0.008089 | -2.820517 | 0.0052 |
| REC | 0.141934 | 0.021267 | 6.673809 | 0.0000 |
| TO | 0.032186 | 0.004670 | 6.892470 | 0.0000 |
| URB | 4.10E-08 | 4.64E-09 | 8.823817 | 0.0000 |
| | **Short Run** | | | |
| COINTEQ01 | -0.006965 | 0.003293 | -2.115262 | 0.0354 |
| D(EG) | 0.002777 | 0.001245 | 2.230656 | 0.0266 |
| D(EG2) | -0.000493 | 0.000121 | -4.060831 | 0.0001 |
| D(REC) | 0.036157 | 0.065410 | 0.552771 | 0.5809 |
| D(TO) | 0.001577 | 0.000639 | 2.469406 | 0.0142 |
| D(URB) | 2.30E-08 | 1.56E-08 | 1.479683 | 0.1402 |

Source: Author calculation

### 4.2.5 Discussions

The present research outcomes indicate that, in the PMG-ARDL long-run analysis, there is a beneficial and substantial association among variables (economic growth, renewable energy consumption, trade openness, and urbanization) on $CO_2$ emissions. However, based on PMG-ARDL outcomes, it shows that the square of EG has a negative effect on $CO_2$ emissions. In this study, the significant levels for the short-run and long-run tests are 1%, 5%, and 10%, corresponding to confidence levels of 99%, 95%, and 90%. The testing criterion is to determine whether the obtained t-probability is less than the significance level. If this is the case, then the obtained variable values have a substantial effect. On the other hand, if the t-probability is greater than the significance level, then the obtained variable values have no significant effect. The outcomes of the study show that economic growth has a positive and significant effect on $CO_2$ emissions in both the long run and short run. The economic growth coefficient is 0.51, and the p-value is 0.0001, which is statistically significant at 1%. In the long run, a 1% rise in economic growth results in a 0.51 increase in carbon emissions. In the short run, economic growth and $CO_2$ have a positive association that is statistically significant at 3%, with a coefficient value of 0.003. A 1% rise in economic growth results in a 0.003 increase in $CO_2$ emissions.The results of Hussain et al., (2022, 2023); Jamil et al., (2022); Raihan et al., (2022); Usman et al., (2023); Zeeshan et al., (2022) are consistent with this conclusion.

The study results indicate that the Environmental Kuznets Curve (EKC) hypothesis validates the sample of the top 10 $CO_2$ emissions countries. Some previous studies support our results (Espoir et al., 2021; Farooq et al., 2022; Jahanger, 2022; Kostakis et al., 2023). Furthermore, based on the study hypothesis, the Environmental Kuznets Curve exists in the top 10 $CO_2$ emitters countries, rejecting the null hypothesis. Economic growth in the top 10 $CO_2$ emitters countries appears to have resulted in higher $CO_2$ emissions. According to the (World Bank, 2020), the top 20 economic growth by country includes the USA, China, Japan, Germany, India, France, Russia, South Korea, Saudi Arabia, and Indonesia. Iran holds the 40th place in economic growth by country. At the same time, these countries contribute to an expansion in $CO_2$ emissions worldwide, accounting for 67.25% (Crippa et al., 2023).

Meanwhile, renewable energy consumption and $CO_2$ emissions have a positive long-run relationship, which is significant at 1% and has a coefficient value of 0.14. However, a 1% enhancement in renewable energy consumption results in a 0.14 increase in $CO_2$ emissions in the long run. Additionally, in the short term, renewable energy and $CO_2$ emissions have a beneficial relationship, but it is insignificant at 5% with a coefficient value of 0.036. Thus, a 1% enhancement in renewable energy consumption leads to a 0.036 increase in $CO_2$ emissions. This implies that in the top 10 $CO_2$ emissions countries, renewable energy consumption is not very effective in reducing $CO_2$ emissions. For these reasons, renewable energy consumptions appears to enhance $CO_2$ emissions based on the outcomes of this study. Some other studies yield similar results (Apergis et al., 2010; Baek, 2016; Menyah et al., 2010). Renewable energy consumptions helps reduce $CO_2$ emissions, but our study's results have confirmed that renewable energy consumption does not contribute significantly to reducing $CO_2$ emissions. According to the (World Bank, 2020), India used 42.30% of renewable energy consumption. Based on our sample, India has a much larger usage of renewable energy. Similarly, Indonesia used 40.26% of renewable energy consumption, while Saudi Arabia only used 0.016%, indicating a low amount of renewable energy usage. Increasing the amount of renewable energy sources is a way to reduce $CO_2$ emissions (Szetela et al., 2022). For instance, the value of the coefficient of trade openness variables has a helpful effect on $CO_2$ emissions over the long run and short run. The supportive association between trade openness and $CO_2$ emissions indicates that a 1% rise in trade openness is associated with a rise in $CO_2$ emissions of 0.032 in the long run, respectively. In the short run, a 1% rise in trade openness results in a 0.001 rise in $CO_2$ emissions. These findings clearly explain that trade openness is the main factor in enhancing $CO_2$ emissions in the top 10 $CO_2$ emitters countries. Similar findings were also found by (Derindag et al., 2023; Dou et al., 2021; You et al., 2022; Zeeshan et al., 2022). Trade openness helps to raise economic growth in a country, but at the same time, based on our study outcomes, it shows that trade openness and carbon emissions have a helpful association. Trade openness contributing to the rise in $CO_2$ emissions in the top 10 $CO_2$ emitters countries is the main contributor to enhancing $CO_2$ emissions. The research outcome shows that urbanization has a beneficial and significant impact on $CO_2$ emissions in our top 10 $CO_2$ emitting countries in the long run. Meanwhile, a 1% improvement in urbanization results in a 4.10 increase in $CO_2$ emissions. In the short run, urbanization and $CO_2$ emissions have a positive association but are statistically insignificant. A 1% increase in urbanization results in a 2.30 rise in $CO_2$ emissions. According to the results, effective urbanization in the top 10 $CO_2$ emitters countries will lead to an increase in $CO_2$ emissions, particularly in the long run. These findings are consistent with previous studies (Afriyie et al., 2023; Bosah et al., 2021; Khoshnevis Yazdi et al., 2019). The present research outcomes are more effective in the long run. China has the highest average urbanization value (565 million), while Saudi Arabia has the lowest average urbanization value (20 million). The study outcomes show that urbanization increases $CO_2$ emissions in the top 10 $CO_2$ emitters countries. Therefore, steps are required to reduce the carbon emissions in the top 10 $CO_2$ emitters countries. In this scenario, economic growth is no doubt important for country development, but it must be utilized with factors related to sustainability to safeguard the environment. To avoid importing or exporting products that could damage environmental quality, there should be more use of renewable energy consumption and the formulation of better policies for urbanization to preserve environmental quality. The estimated coefficient of the error correction term, as apparent in the short-run estimate, is negative and statistically significant.The estimated value demonstrates that the deviation from the long-run equilibrium in the previous years will be adjusted by 0.6965% annually.

#### 4.2.6 Robustness Test

The FMOLS and DOLS are then used to estimate the long-run relationship between the variables. The FMOLS or DOLS results show that in Table 8, economic growth has a positive relationship with carbon emissions. If there is a 1% increase in carbon emissions, economic growth increases by 0.005 and 0.007 in the FMOLS and DOLS tests, respectively. Similarly, REC has a positive relationship with carbon emissions in the FMOLS test and DOLS test. If carbon emissions increase by 1%, REC increases by 0.31 and 0.39, respectively. Nevertheless, trade openness has a positive relationship with carbon emissions in FMOLS and DOLS tests. If there is a 1% increase in carbon emissions, then trade openness increases by 0.002321 and 0.002106, respectively. While urbanization has a positive relationship with carbon emissions, if there is a 1% increase in carbon emissions, then urbanization increases by 1.79 and 1.91.

FMOLS and DOLS robustness tests are also used in this research to increase the reliability of the PMG-ARDL results. FMOLS and DOLS results are similar to PMG-ARDL results, except that renewable energy consumption results are the same in the short run but different (in terms of insignificance, but the sign is the same) in the long run, and urbanization results are insignificant (the sign is the same, but the value is statistically insignificant). On the other hand, when using heterogeneous cointegrated panel data, the FMOLS estimator can be preferred for robustness testing (Pedroni, 2000).

**Table 8. Robustness Test**

**Fully Modified Least Squares (FMOLS)**

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| EG | 0.005276 | 0.002254 | 2.340258 | 0.0200 |
| EG 2 | -0.000569 | 0.000212 | -2.690431 | 0.0076 |
| REC | 0.310272 | 0.282471 | 1.098421 | 0.2729 |
| TO | 0.002132 | 0.000520 | 4.099141 | 0.0001 |
| URB | 1.79E-08 | 1.82E-09 | 9.821578 | 0.0000 |

Source: Author calculation

**Dynamic Least Squares (DOLS)**

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| EG | 0.007233 | 0.002904 | 2.491015 | 0.0133 |
| EG 2 | -0.000647 | 0.000286 | -2.260072 | 0.0245 |
| REC | 0.387453 | 0.399971 | 0.968703 | 0.3335 |
| TO | 0.002106 | 0.000752 | 2.800757 | 0.0054 |
| URB | 1.91E-08 | 3.42E-09 | 5.586371 | 0.0000 |

Source: Author calculation

# CHAPTER V
# CONCLUSIONS AND POLICY IMPLICATIONS

## 5.1 Conclusion

All around the globe, every country wants to prioritize environmental quality and discourage environmental damage. However, at the same time, economic growth is an indication of a country's development, but sometimes, most countries ignore other factors during economic growth. As a result, carbon emissions have increased in countries and worldwide over the last few decades. Furthermore, it is important to bridge this gap, and this present study aims to investigate the effects of economic growth, renewable energy consumption, trade openness, and urbanization on CO2 emissions in the top 10 CO2 emitters countries. The panel of the top 10 CO2 emitters countries includes China, the United States, India, Russia, Japan, Germany, Iran, South Korea, Saudi Arabia, and Indonesia.

This study explored the effect of economic growth, renewable energy consumption, trade openness, and urbanization on CO2 emissions in the top 10 CO2 emitter countries during the period 1990–2020. The present study utilized the PMG-ARDL model and estimated the long-run and short-run relationships between the variables, while the robustness check was conducted using FMOLS and DOLS. The outcomes of the study show that the panel cointegration test validates cointegration among the variables. The findings indicate that there is robust cointegration between economic growth, renewable energy consumption, trade openness, urbanization, and CO2 emissions.

Furthermore, the present study's outcomes of the PMG-ARDL model indicate that, in the long run, economic growth has a positively influence on CO2 emissions. However, squared EG shows a negative effect on CO2 emissions. These results confirmed the environmental Kuznets curve are validated in the top 10 CO2 emitters countries. The aforementioned results clearly demonstrate that in the top 10 CO2-emitting nations, economic growth, renewable energy consumption, trade openness, and urbanization all positively influence carbon emissions. Based on the findings of the study, we can provide some recommendations for policymakers and stakeholders. No doubt, in the modern era, economic growth is important for a country's development, but for environmental sustainability, the study shows a need to adopt policies aimed at expanding economic activities and investment into vital sectors and reducing carbon emissions in these countries.

Furthermore, for economic activities linked with energy use, more energy use results in more economic growth in a country. According to Our World in Data, (2022), total fossil fuel consumption is 137,236.67 TWh, but the top 10 CO2 emitter countries contribute 92,327 TWh, almost 67.27%. The burning of fossil fuels is responsible for about 90% of worldwide CO2 emissions, according to a study on CO2 emissions from the *Joint Research Centre* (JRC) of the *European Commission* (Olivier et al., 2012; Shayanmehr et al., 2020).

### 5.2 Policy Implications

The present research recommends that policymakers make policies based on study results and data. Energy use (Fossil fuel consumption) enhances economic growth, but at the same time, increases carbon emissions. Therefore, to reduce maximum fossil fuel consumption, in top 10 CO2 emitters countries must regulate tax laws and policies, making it compulsory for each sector to reduce fossil fuels and adopt new sources of renewable energy for economic activities each year, along with more subsidies for renewable energy sources. Policymakers should promote to benefits of renewable energy and provide facilities related to green energy. Policy makers should create policies for short-term, medium-term, and long-term loan schemes for renewable energy sectors and provide economic incentives for renewable energy projects. Policymakers should make policies to encourage green growth by investing in green energy and green technologies. The development and use of renewable energy sources should be given top priority by policymakers, who should also enact regulations pertaining to the use of green energy and discourage the use of fossil fuels.

Policymakers make trade policies based on economic activities and renewable policy. Trade openness promotes economic activities, even so, simultaneously, increases CO2 emissions in the top 10 CO2 emitters countries. If the policy provides subsidies related to renewable energy sources and discourages fossil fuels, economic sectors can easily use sources of renewable energy for the growth of the country's economy. Consider trade agreements that promote environmentally friendly products for import. Policymakers should develop and implement urban planning strategies based on sustainability, including waste management policy, to promote a green plantation system and promote green energy products in households.

## 5.3 Limitations

This study mainly focuses on GDP, renewable energy consumptions, trade openness, urbanization, and CO2 emissions. The panel data were collected from the top ten carbon-emitting countries. Other researchers should investigate energy use, technology use, and fossil fuel variables. They should also utilize alternative proxies for carbon emissions in various countries using the panel dataset. It would also be fascinating to examine various economic sectors and identify which ones use more energy and produce more CO2 emissions. Comparing the results is more effective when using the panel dataset alongside the results from the top ten carbon emitters countries.

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