



Faculty of Economics and Business

**Impact of Non-renewable, Renewable Energy Consumption and
Economic Growth on CO₂ Emissions: Empirical Study of ASEAN-5**

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Impact of Non-renewable, Renewable Energy Consumption and Economic
Growth on CO₂ Emissions: Empirical Study of ASEAN-5

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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ABSTRACT

This study explores the impact of energy consumption on CO₂ emissions in ASEAN-5, aiming to deepen understanding of non-renewable and renewable energy's influence, along with economic growth, on CO₂ emissions. The objectives include (i) analysing the short and long-run impact of consumption of energy types and economic growth on CO₂ emissions, (ii) investigating the non-linear effects of both energies consumption on CO₂ emissions, and (iii) assessing the Environmental Kuznets Curve (EKC) hypothesis. Using Pooled Mean Group (PMG) and panel Non-linear Autoregressive Distributed Lag (NARDL) estimators, we examine data from ASEAN-5 (Thailand, Malaysia, Singapore, Indonesia, Philippines) over 31 years (1990–2020). The PMG results reveal that non-renewable energy consumption and economic growth increase CO₂ emissions, while renewable energy reduces them in the long run. Economic growth alone causes short-term environmental degradation. Panel NARDL findings indicate that higher unclean energy consumption leads to environmental degradation, decreasing it helps to reduce environmental problem in the long run, while increased clean energy consumption reduces CO₂ emissions in long run. Economic growth contributes to higher CO₂ emissions initially, decreasing when growth declines, supporting the EKC theory's long-run applicability. Therefore, policymakers should prioritize green investment for an unclean to green energy transition, with government and non-government agencies playing a crucial role in Communication, Education, and Public Awareness (CEPA) programs.

Keywords: Non-renewable energy consumption, Renewable energy consumption, Economic Growth, CO₂ emissions, EKC hypothesis, Non-linear autoregressive lag estimator

***Impak Penggunaan Tenaga Tidak Boleh Baharu and Tenaga Boleh Baharu Serta
Pertumbuhan Ekonomi Terhadap Pelepasan Karbon: Kajian Empirikal ASEAN-5***

ABSTRAK

Kajian ini meneroka impak penggunaan tenaga terhadap pelepasan CO₂ di ASEAN-5, dengan matlamat untuk meningkatkan pemahaman dalam impak tenaga boleh diperbaharui dan tidak boleh diperbaharui serta pertumbuhan ekonomi terhadap pelepasan CO₂ emission. Objektif kajian ini termasuk (i) menganalisis impak penggunaan jenis tenaga dan pertumbuhan ekonomi terhadap pelepasan CO₂ dalam jangka pendek dan panjang, (ii) mengkaji kesan bukan linear terhadap penggunaan kedua-dua jenis tenaga ke atas pelepasan CO₂, dan (iii) menilai hipotesis Environmental Kuznet Curve (EKC). Dengan menggunakan kaedah Pooled Mean Group (PMG) dan panel Non-linear Autoregressive Lag (NARDL), kami mengkaji data dari ASEAN-5 (Thailand, Malaysia, Singapura, Indonesia, Filipina) selama 31 tahun (1990–2020). Keputusan PMG menunjukkan bahawa penggunaan tenaga tidak boleh diperbaharui dan pertumbuhan ekonomi meningkatkan pelepasan CO₂, manakala tenaga boleh diperbaharui mengurangkan pelepasan tersebut dalam jangka panjang. Pertumbuhan ekonomi turut menyebabkan degradasi alam sekitar dalam jangka pendek. Penemuan Panel NARDL menunjukkan bahawa peningkatan penggunaan tenaga yang tidak bersih menyebabkan degradasi alam sekitar, manakala mengurangkannya dapat membantu mengurangkan masalah alam sekitar dalam jangka Panjang. Selain itu, peningkatan penggunaan tenaga bersih mengurangkan pelepasan CO₂ dalam jangka panjang. Pertumbuhan ekonomi menyumbang kepada peningkatan pelepasan CO₂ pada awalnya, dan akan berkurang apabila pertumbuhan ekonomi menurun. Penemuan ini menyokong kerelevanan teori EKC dalam jangka panjang. Oleh itu, penggubal dasar seharusnya memberi keutamaan kepada pelaburan hijau untuk melakukan

peralihan tenaga dari yang kotor kepada hijau. Akhir sekali, kerajaan dan agensi bukan kerajaan memainkan peranan penting dalam program Komunikasi, Pendidikan, dan Kesedaran Awam (CEPA) atas transaksi tenaga.

Kata kunci: *Penggunaan tenaga yang tidak boleh diperbaharui, Pengeluaran tenaga yang boleh dipulihkan, Pertumbuhan ekonomi, Pelepasan CO₂, hipotesis EKC, Kaedah Non-linear Autoregressive Lag*

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LIST OF ABBREVIATIONS

ARDL	Autoregressive Distributed Lag
ASEAN-5	Association of Southeast Asian Nation Five Countries
C2ES	Center for Climate and Energy Solutions
CADF	Cross-section Augmented Dickey Fuller
CD test	Cross-sectional Dependence Test
CIPS	Cross-section Im-Pesaran-Shin
CO ₂	Carbon Dioxide
EKC	Environmental Kuznets Curve
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
NARDL	Non-linear Autoregressive Distributed Lag
NICCDIES	National Integrated Climate Change Database Information and Exchange System
PMG	Pooled Mean Group
R&D	Research & Development
RECs	Renewable Energy Certificates

CHAPTER 1

INTRODUCTION

1.1 Introduction

Global warming and climate change are causing significant environmental impacts, with human activities like fossil fuel usage driving these effects. Satellite data shows the disappearance of glaciers, elevated sea levels, and frequent wildfires (European Space Agency, 2022). The Intergovernmental Panel on Climate Change in 2022 (IPCC, 2022) has declared a "Code Red for Humanity" to address climate change, highlighting the vulnerability of 3.3 billion people and biodiversity decline. The energy sector is the main focus, with 25% of global energy consumption coming from renewables in 2023. The relationship between non-renewable, renewable energy consumption, economic growth and environmental degradation is crucial, with the ASEAN-5 region being a key focus.

The Association of Southeast Asian Nations (ASEAN) was established on August 8, 1967, in Bangkok, Thailand, through the ratification of the ASEAN Declaration or Bangkok Declaration. Thailand, Indonesia, Malaysia, the Philippines, and Singapore were the founding members of ASEAN. The ASEAN-5 countries, which were chosen for their economic development relative to other ASEAN members, established this region. Having been the organization's architects, they continue to be the most influential ASEAN members in the twenty-first century (Zhu et al., 2016).

The rationale behind choosing the ASEAN-5 countries for examination in this study is multifaceted. Firstly, these nations boast a combined population exceeding 680 million, representing a substantial portion of the global workforce, ranking just behind India and

China (World Population Review, 2022). Notably, Indonesia leads the pack in terms of GDP, reaching 1.19 trillion dollars in 2021, with Thailand and Singapore closely following with 505.98 billion dollars and 396.99 billion dollars, respectively (Asia Fund Managers, 2022; Trading Economics, 2022). Moreover, the 2021 ASEAN Power Update reports indicate that Indonesia, Thailand, Malaysia, Philippines, and Vietnam possess the largest installed power capacities, underscoring their significance in the realm of energy (ASEAN Power Update, 2021). The correlation between robust economies and substantial energy consumption makes these countries pivotal subjects for our study. Secondly, these nations are endowed with abundant natural resources and have implemented economic policies that attract significant foreign investment. Consequently, the region has emerged as one of the world's fastest-growing economies (Tuna & Tuna, 2019). The convergence of thriving economies, substantial usage of energy, and strategic economic policies makes the ASEAN-5 countries highly pertinent for an in-depth analysis of the intricate relationship between energy consumption and CO₂ emissions.

Furthermore, energy serves as a critical force propelling economies and societies at global and local scales, exerting influence on the attainment of Sustainable Development Goals (SDGs), with a particular focus on SDG 7 (ensuring access to affordable and clean energy) and SDG 13 (taking action against climate change). Its significance is underscored in poverty reduction (SDG 1), educational empowerment (SDG 4), and healthcare (SDG 3), while the shift to renewable energy in specific regions holds the potential for job creation and the establishment of sustainable communities (SDG 11). However, the utilization of energy, especially non-renewable sources, introduces health and environmental risks, impacting agriculture and exacerbating issues like food security problem. Achieving SDG 7 requires collaborative efforts, recognizing the interconnected nature of SDGs and

emphasizing holistic, interdisciplinary approaches to address socio-economic and environmental challenges.

Renewable energy emerges as a crucial and effective solution for mitigating CO₂ emissions, surpassing fossil fuels in cleanliness and sustainability. Globally, it has become the primary source for new power capacity additions, with many countries integrating significant shares of renewables into their grids. Renewable energy, as a crucial participant in the supply side, is essential for accomplishing the goal of the Paris Agreement. In the context of ASEAN, the region stands to gain from global trends in renewable energy. According to the International Renewable Energy Agency, by 2025, ASEAN countries could generate clean electricity at a lower cost than non-renewable sources. The abundant renewable energy resources in the region, particularly solar thermal and modern bioenergy, offer cost-effective opportunities for deployment, especially in heating and cooking applications. As ASEAN progresses into Phase II (2021-2025) of the ASEAN Plan of Action for Energy Cooperation, the focus shifts towards building the ASEAN Power Grid, expanding multilateral electricity trading, and increasing the share of renewable energy for a resilient and sustainable energy future in line with climate change mitigation efforts.

Therefore, despite the severe impact of the Covid-19 pandemic on ASEAN economies, leading to a downgrade in the economic growth forecast from 4.4% to 4.0% in 2021 due to pandemic restrictions imposed by some ASEAN countries to curb the virus's spread, the region is poised for sustained and robust economic growth. According to the Asian Development Bank (ADB, 2021), the economic growth is projected to increase to 5.2% in 2022, surpassing the global average. This growth trend is expected to persist in the following decade. However, the concomitant strong economic growth, driven by rising

income levels and population expansion, is anticipated to result in increased energy consumption. This, in turn, implies a significant rise in greenhouse gas (GHG) emissions, particularly CO₂ emissions, leading to environmental degradation. Therefore, the role of ASEAN in shaping the trajectory of climate policy on a global scale becomes pivotal in achieving lower emissions solutions.

1.2 Background of ASEAN-5

1.2.1 CO₂ Emissions in ASEAN-5

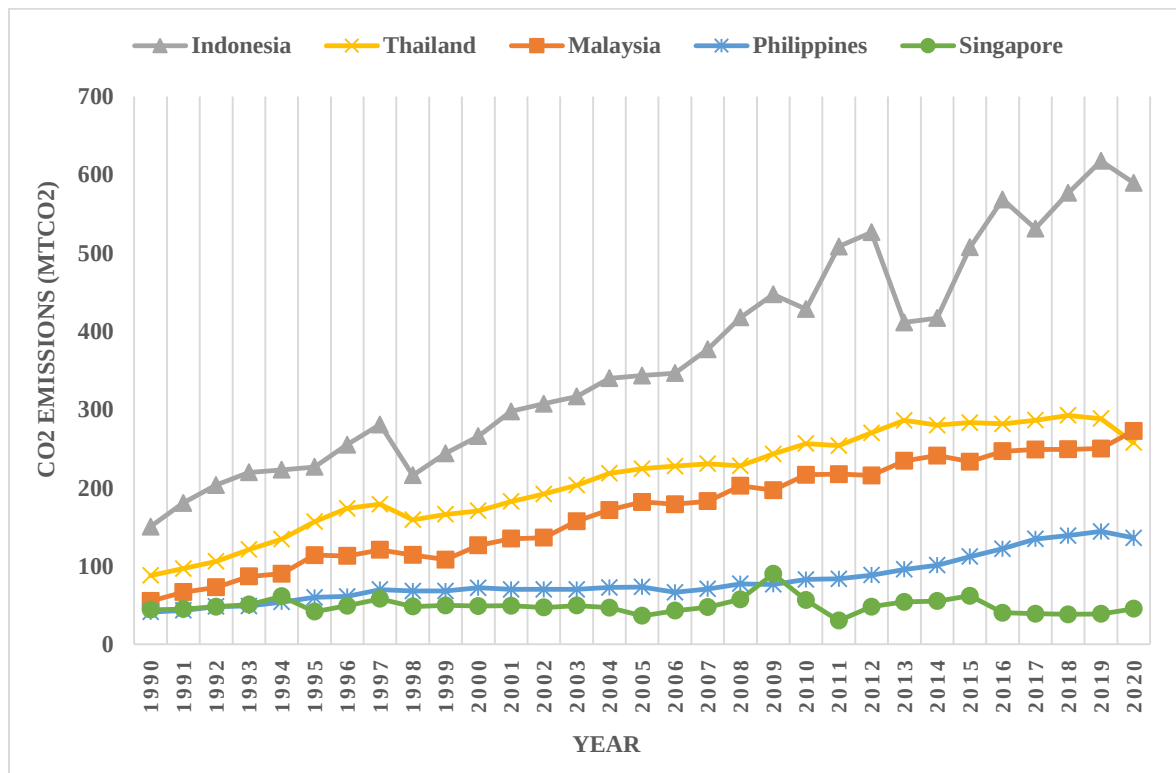


Figure 1.1: CO₂ emissions (MtCO₂) of ASEAN-5 Countries (1990-2020)

Source: Global Carbon Atlas (2022)

Figure 1.1 shows the CO₂ emissions from ASEAN-5 countries, which comprise around 95% of ASEAN GDP. Based on the Figure 1.1, 4 out of 5 countries had experiencing raising in CO₂ emissions, meanwhile Singapore shows a sign of decreasing in CO₂

emissions. In 1998, all ASEAN-5 nations experienced a decline in CO₂ emissions, particularly Indonesia, which exhibited the most significant reduction at 64.77 MtCO₂, surpassing Thailand (19.82 MtCO₂), Singapore (9.72 MtCO₂), Malaysia (6.58 MtCO₂), and the Philippines (1.8096 MtCO₂). The reduction in CO₂ emissions across these countries can be attributed to the financial crisis of 1998. The crisis led to a sharp decline in oil and gas prices, impacting the respective sectors significantly. Diminished demand, coupled with a contraction of credit for purchases, lower corporate earnings resulting in layoffs, contributed to the observed decrease in emissions during this period.

Following a surge in CO₂ emissions across all ASEAN-5 countries, except Singapore, where emissions dropped to 38.94 MtCO₂ in 2019, innovative carbon capture and storage (CCS) technology played a pivotal role. Implemented in Singapore's power plants and industrial processes, CCS significantly reduced carbon footprints (Linga, 2020). Indonesia, ranking as the world's fourth-largest CO₂ emitter, faces environmental degradation from deforestation, peatland megafires, and fossil fuel combustion. Surpassing Australia, Indonesia leads in global thermal coal exports, aiming to bridge electricity gaps between affluent and less-connected islands. Consequently, Indonesia remains the top CO₂ emitter, followed by Thailand, Malaysia, and the Philippines, while Singapore, utilizing effective carbon capture technology, stands as the least emitter.

1.2.2 Non-Renewable Energy Consumption in ASEAN-5

Figure 1.2 shows the non-renewable energy consumption per capita of ASEAN-5 countries. Based on Figure 1.2, it shows a sign of rising in non-renewable energy consumption for every ASEAN-5 country. Singapore recorded highest non-renewable

energy consumption among ASEAN-5 members, and followed by Malaysia, Thailand, Indonesia and Philippines.

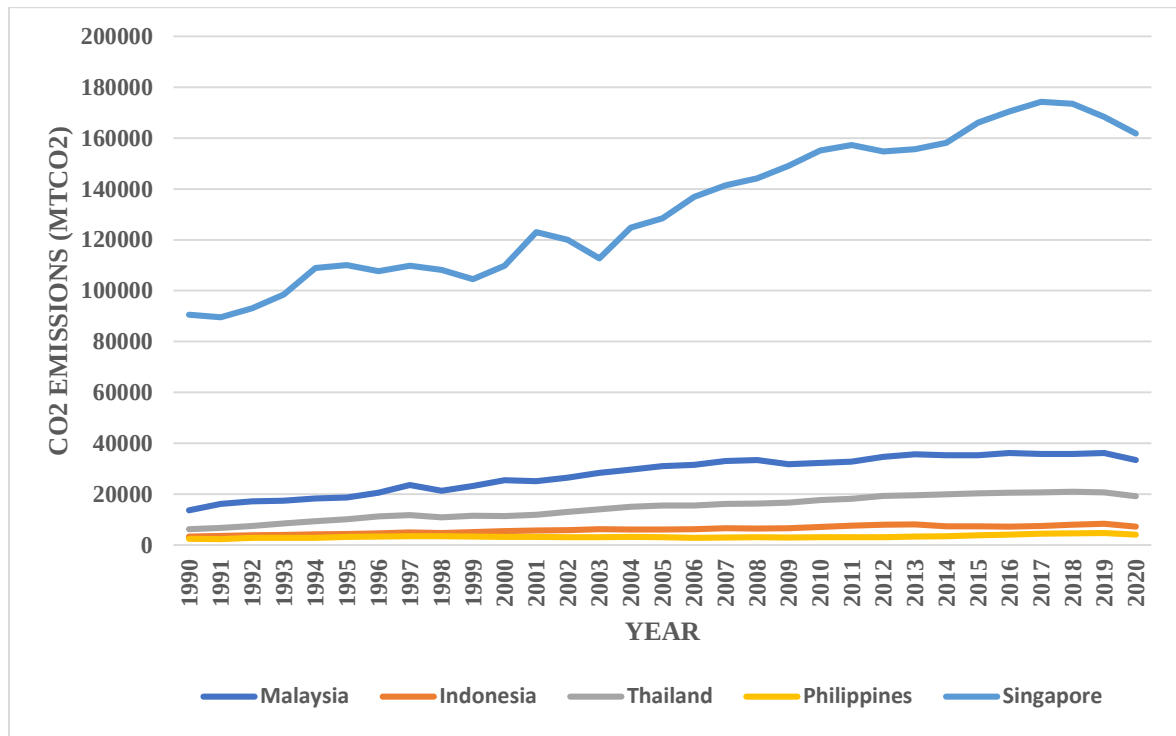


Figure 1.2: Non-Renewable Energy Consumption Per Capita of ASEAN-5 (1990-2020)

Source: Our World In Data (2022)

The reason behind Singapore recorded the highest non-renewable energy consumption due to recognize as the base of major oil companies in the country with ideal trading location and perceived safe environment, for instance the Exxon Mobil company. An analyses of energy tariff comparison platform depicts that most countries depend on fossil fuels and Singapore stand on top of the rank. According to the report from Power Engineering International (2021), Singapore relies on non-renewable energy more than other ASEAN-5 countries, with proximately 98% of total energy supply generated from traditional fuel sources. Singapore consumed large proportion of oil regarding on total energy supply, which the oil equivalent to 73% of energy supply. Increasing energy demand is crucial

towards economic growth as it contributes to GDP of the countries, but rapid increase in non-renewable energy consumption causes more environmental degradation such as rising in CO₂ emissions, as shown in Figure 1.1. As sequence, Singapore recorded highest non-renewable energy consumption among ASEAN-5 members, and followed by Malaysia, Thailand, Indonesia and Philippines.

In contrast, Philippines recorded the lowest non-renewable energy consumption compared to other ASEAN-5 country. Since 1990s, Philippines had suffered electricity outages or shortages, particularly during summer months. Based on United Nations Framework Convention on Climate Change (2016) report, Philippines' electricity demand was rising 25.6 GWh in 1991 2003 to 77.3 GWh in 2014. The supply of primary energy forecasted to be double within 2011 to 2030. However, the energy scarcity has detrimental impacts towards the country's economic growth. According to Santos (2018), the recent challenges that faced by the energy sector related to supply-demand gap that characterized by the unfulfilled demand. Factors that causing unmet demand of energy in Philippines were because of high electricity prices, lack of investment in generation, reduction in self-sufficiency and lastly, expected increase rate in GHG emissions levels. Therefore, the Philippines has adopted a national renewable energy program to significantly increase the generation capacity of renewable energy technologies to achieve energy security in 2030, which also help to mitigating GHGs emissions from power sector.

1.2.3 Renewable Energy Consumption in ASEAN-5

Figure 1.3 shows the renewable energy consumption per capita (kWh) from 1990 to 2020 for the ASEAN-5 countries. According to Figure 1.3, most of the countries reveals that

renewable energy consumption per capita was increasing from 1990 to 2019 and decline in 2020 for Malaysia and Thailand.

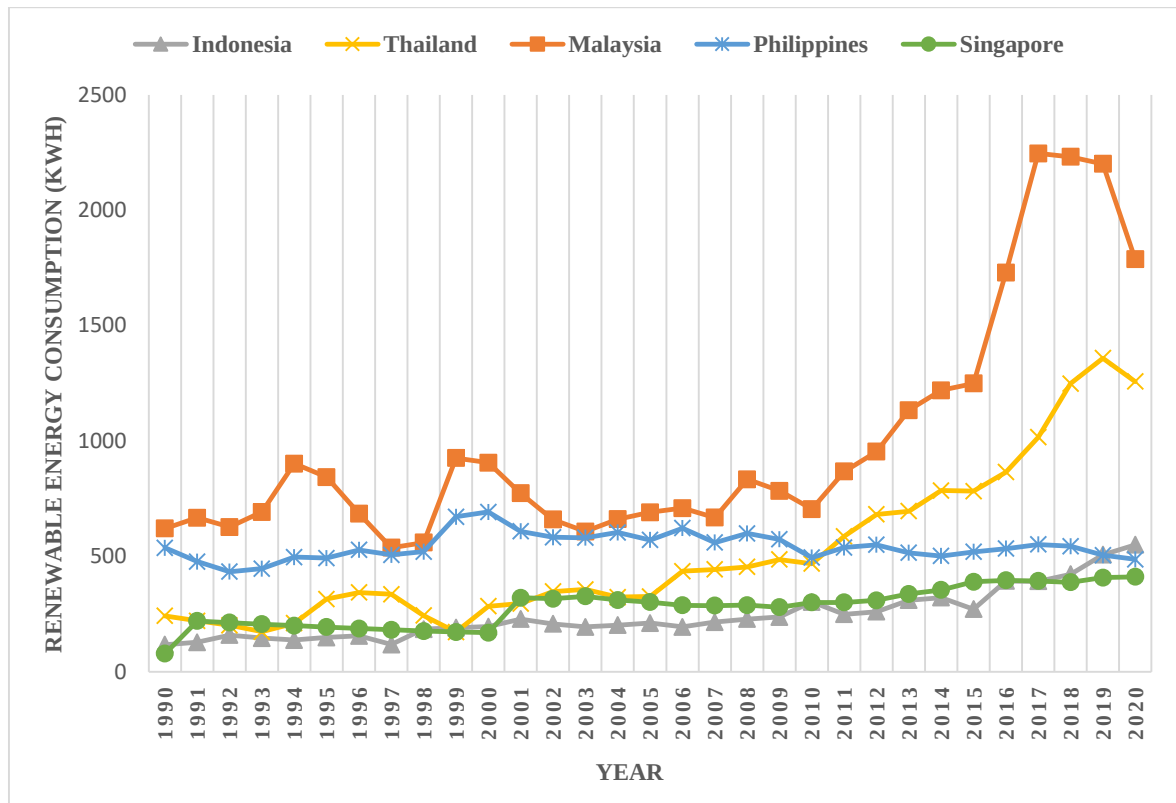


Figure 1.3: Renewable Energy Consumption Per Capita of ASEAN-5 (1990-2020)

Source: Our World In Data (2022)

As shown in Figure 1.3 that Malaysia is among the highest renewable energy consumption as Malaysia considered the leader amongst the members. The renewable energy sector had gained momentum in pursuing the country's National Renewable Energy Policy with Action Plan and the government's feed-in tariff scheme. That is already accelerating the renewable energy consumption in the country. Additionally, both government and private corporations in Malaysia play their key roles in moving the country ahead to renewable and sustainable energy goals. Although Malaysia consists of legislation,

policies, and incentives in place for the renewable energy, however, the government still lack in convincing private companies or industries to make a shift in renewables.

In contrast, Figure 1.3 depicts that Philippines has the lowest rate of increasing in renewable energy consumption, although the country has reached substantial progress in lowering energy intensity of the economy. However, the potential CO₂ emissions reduction was exceeded by rising carbon intensity of energy sector, especially worrying in raising of coal in electricity supply. Philippines recorded lowest in percentage change of renewable energy because the share of renewables declined from 26% to 15% in 2000 and 2015, respectively, despite the current high-capacity additions, namely wind, solar and solid biomass, as stated in Philippines Country Profile (2019). In addition, the Philippines as fossil energy importer and rely heavily on imported oil for transportation industries and coal for energy sector. On the average, about half of Philippines primary energy depend on imported fossil fuels as it is cheaper than others. Thus, Philippines governments should reduce reliance on imported sources of energy to achieved the energy independences which are crucial for the Philippines economy.

1.2.4 Economic Growth in ASEAN-5

In addition, energy consumption exists in pursuit of the objective of economic sustainability. Based on Figure 1.4, all the ASEAN-5 countries demonstrate rising in GDP per capita throughout the three decades. In 1998, all the ASEAN-5 countries' GDP per capita experienced a sharp decline. According to Ba (2021), the reason was due to the financial crisis that hit the Thai baht currency to unpegged in Bangkok, that setting the currency devaluations and massive flights of capital.

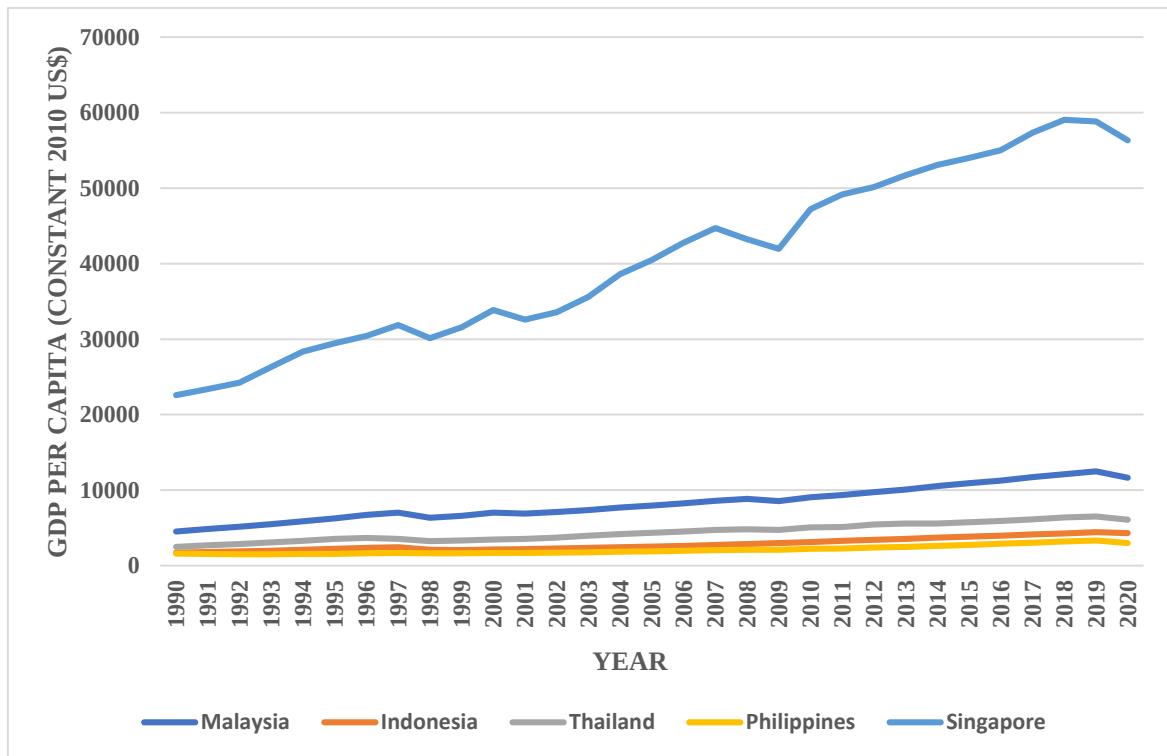


Figure 1.4: GDP per Capita of ASEAN-5 (1990-2020)

Source: World Development Indicator (2022)

Ba (2021) further mentioned that the value of Indonesia Rupiah was down by 80%, Thai baht exceed 50% decline and Malaysian ringgit own by 45%. Conjointly, the economies most affected saw a drop in capital inflows of greater than 100 billion US dollars in the year of crisis.

After the financial crisis event, all the ASEAN-5 countries' economy back to track, which the GDP per capita had been increase within two decades, until 2019, the GDP per capita swelling to 58829.63 US dollars Singapore, 12486.68 US dollars Malaysia, 6094.43 US dollars Thailand, 4312.35 US dollars Indonesia and 2980.02 US dollars Philippines. Towards the year 2020, where all ASEAN-5 countries are facing economic downturn due to Covid-19 pandemic. Based on the report of ASEAN Policy Brief (2020), the novel virus pandemic, Covid-19 had hit ASEAN countries that negatively impact on the economy. The

key sectors mainly affected by tourism, retail, and other services sectors, which almost all the sectors business operations and supply chain disrupted, employment and livelihood put on risk of infection, while the consumer confidence has declined. The Covid-19 outbreak has diminished the prospects of economic recovery from the broad global slowdown.

1.3 Problem Statement

Energy is an indispensable component of the ASEAN-5 economy. Conversely, as non-renewable energy sources, such as fossil fuels, are increasingly utilised, CO₂ emissions increase, giving rise to adverse externalities. Countries in this region, such as Malaysia, Indonesia, and the Philippines, heavily rely on coal consumption, while Singapore primarily uses natural gas, and Thailand utilizes both oil and gas. The energy sector in ASEAN-5 is recognized as the largest emitter of pollutants, posing one of the most pressing challenges faced by humanity. Approximately 90% of the ASEAN's total primary energy requirement is sustained by non-renewable sources like coal, oil, and gas. The demand for these non-renewable energies is projected to increase by 4.7% annually from 2013 to 2035. A significant portion of the oil requirements is imported from outside ASEAN countries, and consumption levels are expected to rise significantly with development and economic growth. Historically, ASEAN has imported around 60% of its oil requirements. According to IRENA and ACE (2016), CO₂ emissions from power generation are anticipated to increase by more than 84% annually, reaching 1 Gigaton each year. Coal is identified as the primary contributor to this growth. The second-largest source of CO₂ emissions is the combustion of oil products, while natural gas, though similar to oil, is projected to contribute less to overall emissions. These patterns underscore the escalating need for fossil fuels in the ASEAN-5 region, notwithstanding their progressive exhaustion, thereby exacerbating the escalation of carbon dioxide emissions.

The increasing CO₂ emissions associated with the use of non-renewable energy sources present a substantial peril of ecological catastrophe in the ASEAN-5 area. For examples, the 2020 Global Climate Risk Index report highlights the Philippines as the second most affected country by climate disasters in 2018, incurring damages totaling 4.5 billion US dollars. Additionally, major islands like Indonesia and the Philippines face the risk of submersion due to rising sea levels, potentially reaching 7 meters if all the ice on Greenland melts. Thailand, a key global rice exporter, confronts threats to its agriculturally productive and densely populated Chao Phraya Delta from salinization. Without substantial technological advancements to address climate vulnerability, rice yields in Indonesia, the Philippines, and Thailand could decrease by 50% from 1990 levels by 2100 due to rising CO₂ emissions. The fact that Malaysia lost \$4.5 billion due to severe flooding caused by extreme weather patterns induced by climate change demonstrates the region's severe dependence on non-renewable energy sources in a tangible and immediate manner. In brief, the increase in CO₂ emissions resulting from the widespread utilisation of non-renewable energy sources exposes the ASEAN-5 nations to an elevated peril of climate-related catastrophes.

Secondly, in recent years, the relationship between energy consumption and CO₂ emissions has been a contentious and critical issue. Numerous scholarly investigations have examined the correlation between CO₂ emissions and the consumption of renewable and non-renewable energy sources (Long et al., 2015; Dogan & Seker, 2016; Ito, 2017; Mbarek et al., 2017; Sharif et al., 2018; Zaidi et al., 2018; Hanif, 2019; Nathaniel & Iheonu, 2019; Araby et al., 2019; Koengkan, 2020; Vural, 2020). The majority of research have indicated that non-renewable energy sources are associated with higher levels of CO₂ emissions. As a result, governments can predominantly achieve their net zero emission goals by transitioning

from non-renewable energy sources to cleaner alternatives. It is because renewable energy did not or release small amount of CO₂ emissions that will harm the environment. Nevertheless, the majority of these prior investigations solely focused on the linear ramifications of renewable and non-renewable energy source consumption, economic growth, and environmental deterioration (linear models frequently denote direct connections between variables owing to their simplicity and interpretability, which renders them appropriate for certain economic scenarios). But lack of non-linear linkage between disaggregate energy consumptions and CO₂ emissions (non-linear models are employed when relationship is more complex, capturing situations where the impact of changes is not constant or uniform).

What will happen to these energy consumptions in ASEAN-5 if the energies consist of non-linear impact on the greenhouse gases, the literature is still lack on the information. The extant body of literature faces difficulties in furnishing reliable and precise data regarding the degree of the non-linear correlation between the consumption of non-renewable and renewable energy sources and CO₂ emissions in the ASEAN-5 countries. It is important to conduct the non-linear analysis as it is best to further understand the trend performance that can be clearly see the movement of the studied variables over the time. Non-linear study also helps in finding more refined solutions to the actual unsolved problems or the ambiguities in the economics.

Thirdly, the persistent challenge lies in the apparent discord between economic growth and the reduction of CO₂ emissions, primarily attributed to the inseparable link between emissions and economic prosperity through escalating energy consumption. Notably, the surge in energy consumption accompanying economic growth, predominantly

fuelled by fossil sources, emerges as the central driver behind the escalating CO₂ emissions (Liobikiene & Butkus, 2018). Adding to this matter is the absence of a definitive corpus of literature concerning the correlation between economic development and CO₂ emissions in the ASEAN-5 region, which further complicates the relationship between energy, growth, and the environment. In contrast to the EKC hypothesis, which posits a curvilinear relationship between CO₂ emissions and economic development, whereby emissions are anticipated to decline beyond a particular economic threshold, conflicting evidence continues to exist. The EKC hypothesis has been investigated in many research, with Khalid and Muhammad (2013) proposing a linear relationship, while Heidari et al. (2014) and Farooq et al. (2020) argue for its presence in the ASEAN region. Conversely, several studies (Chang & Tang, 2013; Zhu et al., 2016) have been unable to furnish substantiating evidence regarding the applicability of the Environmental Kuznets Curve (EKC) hypothesis within the ASEAN context. The inconclusive nature of these studies can be attributed to variations in analytical samples, disparate forecasting models or methods employed, and the diverse array of control variables integrated into the models (Zhu et al., 2016). Consequently, the limited and conflicting evidence fails to establish a dominant narrative elucidating the Environmental Kuznets Curve's applicability, rendering the understanding of its validity inconclusive within the ASEAN-5 context.

1.3.1 Research Gap

By examining the non-linear relationship between the consumption of non-renewable energy, renewable energy, economic growth, and CO₂ emissions, this research endeavours to identify any deficiencies in the existing body of literature. The majority of researchers concentrate on developed and developing economies in MENA, GULF, Asia, Africa, and Europe. To evaluate the impact of renewable energy consumption, non-

renewable energy consumption, and economic growth on CO₂ emissions, the current study employs a non-linear analysis of the ASEAN-5 countries, which have been afforded less attention in prior research. A comprehensive analysis of the interplay between energy consumption, economic growth, non-renewable and renewable energy consumption, and energy consumption is imperative in the ASEAN region due to the substantial impact that energy consumption has on CO₂ emissions. The EKC hypothesis requires further investigation in the ASEAN-5 countries, which have not been adequately examined in previous studies. Therefore, it is crucial to examine the EKC for environmental sustainability in the ASEAN-5 countries. This work will offer a fresh perspective on non-linear relationships within panel data, utilising an econometric technique that is resilient to time instability and cross-sectional variability.

Moreover, the capacity of research to provide comprehensive insights into the correlation between energy consumption and CO₂ emissions is constrained by the linear nature of OLS regression approaches. The validity of the non-linear effects of non-renewable energy consumption, renewable energy consumption, and economic growth on CO₂ emissions in the ASEAN-5 countries will be evaluated in this study using panel non-linear ARDL. Econometric methodology is capable of discerning the non-linear cointegration relationship that exists between disaggregated energy consumption and economic growth. Additionally, it can assess the effects of positive and negative shocks on CO₂ emissions across various time periods, encompassing both short and long durations. This approach goes beyond the exclusive reliance on linear analysis.

1.4 Research Questions

As the problem statements arise, there are 3 research questions had been formed based on the research issues of this study.

- i. What will be the impact of renewable and non-renewable energy consumption on CO₂ emission in long-run and short-run?
- ii. What would be the non-linear impact of non-renewable and renewable energy consumption on CO₂ emissions?
- iii. Does EKC hypothesis exist in the case of ASEAN-5 countries?

1.5 Objective of the Study

The formulation of the study's general purpose and specific objectives was guided by the research questions that were previously mentioned. The principal objective of this study is to investigate the impact of economic growth, non-renewable and renewable energy consumption, and CO₂ emissions in the ASEAN-5 countries.

1.5.1 Specific Objective of Study

As the research questions arise, the specific objectives of the study are:

- i. To examine the impact of non-renewable energy consumption, renewable energy consumption and economic growth on CO₂ emission for the short-run and long-run in ASEAN-5 countries
- ii. To investigate the non-linear impact of non-renewable and renewable energy consumptions on CO₂ emissions for ASEAN-5 countries
- iii. To assess the EKC hypothesis for the case of ASEAN-5 countries

1.6 Significance of the Study

The current study mainly offer three contributions. Firstly, the outcome of the study will help the policymaker of each ASEAN-5 countries such as, Ministry of Energy and Natural Resources and Ministry of Energy, Green Technology and Water in Malaysia, Ministry of Energy and Mineral Resources in Indonesia, Department of Energy in Philippines, Ministry of Energy in Thailand and Energy Market Authority in Singapore, that all have the similar responsibility in integrated action mechanisms incorporating the policy formulation towards the better environmental quality by using the cleaner and greener energy mix from the existing energy sectors. Indirectly, the policymakers also able to share the information towards society especially residences and business premises regarding different energy consumption would contribute different level of CO₂ emission that brings environmental problems. It is collective responsibility in achieving the CO₂ emissions reduction for the better future of environment.

Additionally, this study aims to address the current dearth of evidence by examining the validity of the non-linear correlation between the consumption of non-renewable and renewable energy sources and the CO₂ emissions of the ASEAN-5 nations. The trade and urbanization will act as control variable in this model to deal with the omitted variables bias problem. Investigating the non-linearity of the selected variables able to provide the information of how the CO₂ emission that emitted will happen on non-linear impact from disaggregate energy consumption and best way to further understand the trend performance that can clearly see the movement of the variables overtime. It also aids policymakers in comprehending not only the linear influence on CO₂ emissions, but also the non-linear influence of energy consumption on CO₂ emissions. This understanding can assist in identifying more sophisticated solutions for addressing the current climate change issues and

environmental degradation in nations. Thus, this objective will contribute to the field whereas it delivers the first finding of the possibility of non-linearity relationship among the variables, and it help the mentioned department and ministry of energy in ASEAN-5 countries to further planning regarding important of the role of each energy consumption towards future CO₂ emission reduction goal.

Thirdly, the recent literature of the EKC shows there are lack of studies had tested the EKC on ASEAN-5. Under the aegis of the EKC hypothesis, the present study will thus contribute to the scant literature concerning the energy-growth-environment relationship for ASEAN nations. Long-term and short-term nonlinear effects of renewable and non-renewable energy sources, in conjunction with economic growth, on the increase in CO₂ emissions in the ASEAN-5 countries are investigated in the present study. Recently, some studies had analysed on the nexus of energy consumption at disaggregate level, economic growth and CO₂ emission, while most of the studies literature had ignore on investigating the panel of ASEAN-5 countries. These unexpected findings serve as the impetus for this study's in-depth examination of the ASEAN-5 nations in an effort to identify new policies or strengthen existing ones concerning economic growth and energy balance. Besides that, the outcome of the study also able to provide in-depth knowledge of energy-growth-environment nexus in EKC framework ASEAN-5 non-linear trend of CO₂ emission. The policymakers of ASEAN-5 also might manage to make an efficient planning and action for future sustainable economics in boosting environmental quality based on economic behaviours and energy consumption. Thus, the outcome of this study would be able to give useful information not only to the policymakers in drafting better environmental and business policies, but the finding also acknowledges the society to understand it is important in deeply concern and taking part in mitigating climate disaster.

1.7 Organization of the Study

The study will be organized as following: in chapter one will describe the background of ASEAN-5's consumption of both energy and CO₂ emissions, then in further address on the problem statements, research questions, the objectives of studies and the contribution of the study. Whilst, in chapter two will reviews the related previous study on energy-growth-environment nexus that been done by many researchers in different countries and regions. Moreover, it will divide into four sections that include theoretical framework, conceptual framework, empirical finding and concluding remark. In chapter three will be focus on panel data and methodology that will be use in the study. Chapter four will be analysed and interprets the empirical results. Lastly, in chapter five will concludes overall finding and provides policy recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The importance of energy in contributing to the economic well-being and development of countries cannot be questioned. An inadequate amount of scholarly literature exists concerning the correlation between the utilisation of renewable and non-renewable energy sources, economic development, environmental deterioration, and economic growth in China, India, the United States, Pakistan, Sub-Saharan Africa, OECD nations, EU member states, and ASEAN nations. These studies predominantly focus on time series and panel data analysis.

As opposed to renewable energy, which serves to alleviate environmental degradation, the overwhelming majority of the available literature suggests that the utilisation of non-renewable energy sources has contributed to the degradation of environmental quality (Shabbir et al., 2011; Long et al., 2015; Dogan & Seker, 2016; Mbarek et al., 2017; Ito, 2017; Chen et al., 2018; Sharif et al., 2018; Zaidi et al., 2018; Leal, 2018; Souza et al., 2018; Bekun et al., 2019; Bilan et al., 2019; Nathaniel & Iheon, 2019; Fatima et al., 2020; Erkisi & Celik, 2020). The combustion of non-renewable energy sources, such as fossil fuels, generates a greater quantity of greenhouse gases (GHGs), specifically CO₂ emissions, according to the studies. As a consequence of the increase in energy demand and CO₂ emissions, environmental degradation occurs in the form of extreme temperatures, sudden floods, and typhoons, among others. Nonetheless, numerous scientists conclude that increasing the proportion of renewable energy sources would reduce CO₂ emissions. This implies that renewable energy sources offer viable solutions to both environmental and

energy security concerns. An increase in the utilisation of renewable energy sources has the potential to bolster national energy security and diminish dependence on fossil fuels, as stated by Fatima et al. (2020). As reliance on non-renewable energy sources decreases and there is a transition towards the installation and utilisation of renewable energy sources, environmental quality will reach a critical juncture in its restoration, while CO₂ emissions will begin to decline. It illustrates how renewable energy sources, including hydropower, are more environmentally friendly than fossil fuels.

In Chapter 2, it will be divided into five sections; theoretical framework will discuss in Section 2.2 while Conceptual framework will be mentions in Section 2.3. The empirical finding of the study will be explained in Section 2.4. Moreover, Section 2.5 will review on concluding remark of Chapter 2.

2.2 Theoretical Framework

2.2.1 Environmental Kuznets Curve (EKC) Hypothesis

The Environmental Kuznets Curve hypothesis emphasized the nexus between environmental problem and economic development that plotted as inverted U-shaped and originally proposed by Simon Kuznets (1955). Besides, Grossman and Krueger (1991) are the first authors that test the EKC hypothesis between various indicators of environmental pollution and economic development. The outcome of their work determined that there is a valid inverted U-shape relationship exist for dark matter, sulfur dioxide and other suspended particles. Based on the EKC hypothesis, increase in the economic development will lead to raising in environmental degradation at the first level. However, after passing certain threshold level, increasing in economic development will reduce environmental degradation.

Moreover, there are some researchers able to use energy intensity as the factor that determined the EKC hypothesis (Kaika & Zervas, 2013; Chen et al., 2019; Pata, 2020).

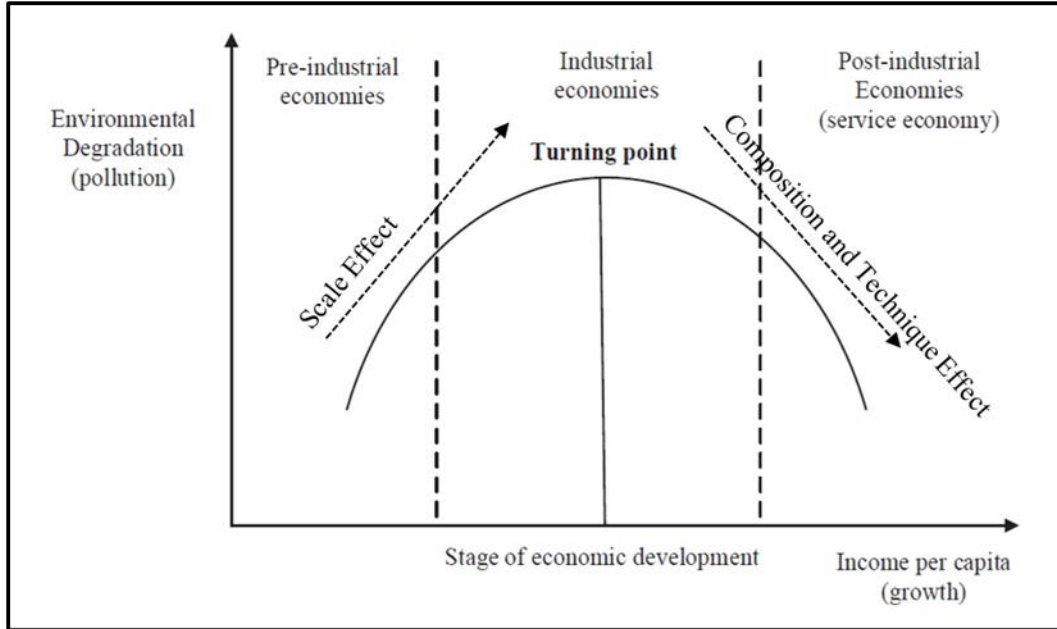


Figure 2.1: Environmental Kuznets Curve (EKC)

Source: Chen et al. (2019)

As per this hypothesis, EKC can be classified into three primary stages, each of which is determined by the level of pollution. The initial phase pertains to pre-industrial civilizations, characterised by a swift escalation in pollution and limited economic progress. This is because in this stage increase in extraction of natural resources especially fossil fuels and production of energy are the result in generating the pollution, that called as scale effect of production on environment. Based on Figure 2.1, scale effect led to upwards trend of EKC whereas the production is shift from pre-industrial production to industrial production. During industrial production process, immoderate consumption of fossil fuels sources such as oil, coal and natural gas will emit more pollutant particle especially CO₂ emission that cause difficulty in sustainable growth because it led to problem of climate change and

ecological imbalances. As economic development raising from pre-industrial to industrial, further consumption of fossil fuels resources will bring greater environmental issues.

During the industrial economy stage, which is the second stage, inhabitants acquire disposable income that becomes more affordable, enabling them to initiate the adoption of non-fossil energy sources. This phase is regarded as the critical juncture in the era of environmental quality. The economic development also provides opportunity to invest in information-based industries and services to improve the production technique that able to use cleaner technology. These effects are called as composition and technique effect, respectively. Effect of composition that link to shift in production patterns from material and energy-intensive services to more environmentally friendly sector (Kaika & Zervas, 2013). These effects are used to against the scale effect and generate downward trend of EKC, as shown in Figure 2.1.

In the stage of post-industrial economies, as the final stage, environmental degradation is further reduced, as depicts in Figure 2.1. Due to technique effect, there is an improvement of technology used that able the consume less inputs per unit of output, in other meaning the use of cleaner technologies that shifted from traditional and dirtier technology in production of energy. Jebli et al. (2016) mentioned that renewable energy sources are unlike fossil fuels because it is clean, inexhaustible and environmentally friendly. With great extensive increase in fossil fuels consumption led to disastrous and destructive towards environment, thus, renewable energy will be replacing in this stage to improve quality of environment and give energy security as well as diversity.

When come to energy, most of the empirical study associated with EKC demonstrate a rather positive relationship among energy, economic growth and CO₂ emissions (Long et

al., 2015; Jebli et al., 2016; Ali et al., 2017; Zaidi et al., 2018; Zafar et al., 2019; Vural, 2020). It describes that energy accompanies economic growth, meanwhile most of energy based on non-renewable resources such as fossil fuels are main factor of human-related CO₂ emissions. Despite, focusing on reducing energy consumption to mitigate CO₂ emissions can negatively impact economic growth (Chontanawat et al., 2008).

2.3 Conceptual Framework

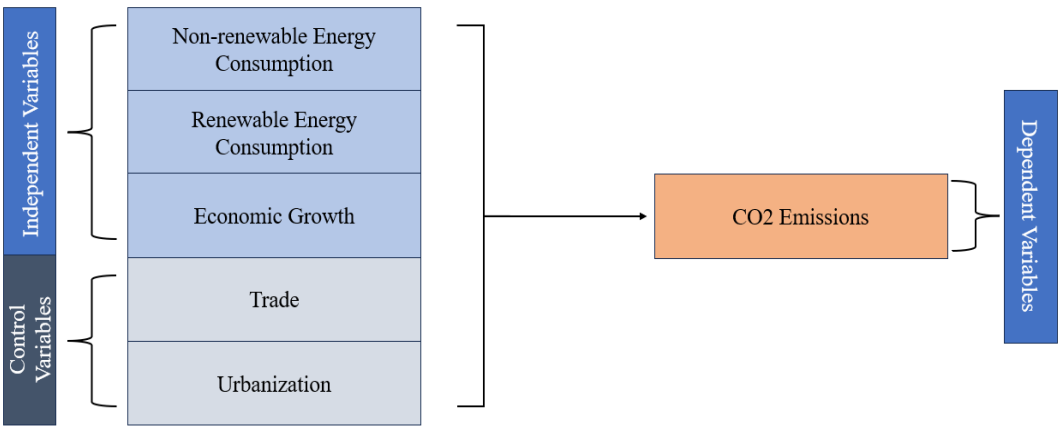


Figure 2.2: Conceptual Framework

An examination of the impact of non-renewable energy, renewable energy, and economic growth on CO₂ emissions in the ASEAN-5 is depicted in the conceptual framework shown in Figure 2.2. The aforementioned conceptual model effectively illustrates the initial paradigm of the research inquiry. Economic expansion, nonrenewable energy consumption, and renewable energy consumption are all considered independent variables in the study. These independent variables are the direct impacts towards environmental degradation. The study can say that environmental degradation that cause by rising in greenhouse gases is the deterioration of the environment via the consumption of natural resources such as fossil fuels that will be exhausted, which is mainly caused by the human

activity. Still, the mitigation on studied gases needs to be crucially considered in order to save the Earth. While there are various environmental degradation indicators, this study will only use the main cause of negative externalities: CO₂ emissions. Simultaneously, the study also uses some of the control variables: trade and urbanization to enhance the internal validity of the study by lowering the influence of other extraneous variables and obtain robust results.

2.4 Empirical Findings

There are various of studies that examine the nexus among non-renewable and renewable energy sources of consumption as well as economic growth on CO₂ emissions for different countries and regions. Thus, the empirical findings of this study will be divided into three parts based on single countries, panel countries and ASEAN regions.

2.4.1 Country Level Studies of Non-renewable Energy Consumption, Renewable Energy Consumption, Economic Growth and CO₂ Emissions Nexus

An increase in CO₂ emissions is directly linked to the use of non-renewable energy sources, especially in developing countries where this usage is on the rise. Therefore, the environmental quality will degrade as a result of the rising concentration of CO₂ emissions. Using renewable energy sources to create power with minimum or no CO₂ emissions helps reduce CO₂ emissions. Aremu (2014) evaluated Nigeria's economic growth between 1981 and 2011 by examining its energy consumption and CO₂ emissions. The results of the Granger causality analysis indicate that energy consumption influences CO₂ emissions in a unidirectional fashion, while economic growth influences energy consumption in a bidirectional fashion. In the findings, the long-term relationship between the variables and the effect of energy on economic development is evident.

From 1952 to 2012, Long et al. (2015) examined the relationship between renewable and non-renewable energy, CO₂ emissions, and economic growth in China. The Granger causality method demonstrates that GDP and coal, gas, CO₂ emissions, and power consumption are bidirectionally related. According to both static and dynamic regression models, the relationship between coal consumption and economic growth and carbon emissions is preponderantly asymmetric, whereas oil consumption positively affects CO₂ emissions. Hydropower and nuclear power have been documented to exert a positive influence on CO₂ emissions as a result of their implementation of impulse response systems. Chen et al. (2018) use a Granger causality test based on VECM to examine the correlation between per capita CO₂ emissions, GDP, renewable and non-renewable energy production, international trade, and renewable and non-renewable energy production in China from 1980 to 2014. By integrating the EKC theory, the authors discovered evidence that an inverted U-shaped EKC hypothesis has a prolonged duration. A positive correlation exists between non-renewable energy and GDP and CO₂ emissions, while a negative correlation is observed between renewable energy and international trade and CO₂ emissions. The Granger causality test demonstrates that international trade and renewable energy usage, as well as foreign trade and GDP, have a bidirectional relationship in the near term. At present, their sole transient correlation pertains to the utilisation of renewable energy sources, an area that is influenced by international trade and economic expansion.

Jebli and Youssef (2015) investigated the correlation between CO₂ emissions, economic development, the utilization of renewable and non-renewable energy sources, and trade in Tunisia from 1980 to 2009. Their study findings, employing ARDL and VECM, suggest that trade, GDP growth, CO₂ emissions, and non-renewable energy have a short-term one-way causal connection with renewable energy. Moreover, the utilization of

renewable energy has minimal and adverse impacts on CO₂ emissions. Long-term evidence is inadequate to substantiate the EKC hypothesis. In line with the research conducted by The present study investigates the relationship between economic development, environmental degradation, and the use of renewable and non-renewable energy sources in Tunisia from 1990 to 2015, as described by Mbarek et al. (2017). The outcomes of the Granger causality test indicate that the utilisation of renewable energy and the emission of CO₂ are both causally related, as is the consumption of energy with respect to the release of CO₂ emissions. A unidirectional causal relationship has been established between energy consumption and per capita GDP growth, in addition to between CO₂ emissions and the adoption of renewable energy sources. The VECM analysis demonstrates that renewable energy has a positive impact on GDP, while CO₂ emissions have a significant negative influence.

Bulut (2017) conducted a research in Turkey to analyse how different energy sources, such as renewable and non-renewable, affected CO₂ emissions from 1970 to 2013. The findings show that renewable power reduces CO₂ emissions, but non-renewable electricity increases CO₂ emissions. Erkisi and Celik (2020) conducted a study from 1990 to 2015 examining the correlation of CO₂ emissions, non-renewable energy usage, and economic development in Turkey. The VAR Granger Causality study shows a one-way causal link in the near term between the usage of non-renewable energy sources and CO₂ emissions. Their study supports the Neutrality Hypothesis for Turkey, suggesting that there is no causal link between the variables. Dogan and Ozturk (2017) analysed the effects of renewable and non-renewable energy usage, real income, and CO₂ emissions in the United States from 1980 to 2014. According to research, increased reliance on non-renewable energy sources increases CO₂ emissions, while increased utilisation of renewable energy decreases CO₂ emissions.

The United States has yet to formally validate the EKC theory, which is consistent with the findings of Jebli and Youssef (2015).

Utilising a structural VAR approach, Shabbir et al. (2011) analysed the relationships between renewable and non-renewable energy consumption, real GDP, and CO₂ emissions in Pakistan from 1971 to 2010. Research findings indicate that 87% of CO₂ emissions come from non-renewable energy sources, intensifying the impact on economic activity. The augmentation of renewable energy sources is imperative in order to bolster economic growth and facilitate the expansion of real GDP. Analogous to the results reported by Zaidi et al. (2018) in Pakistan spanning the years 1970 to 2016. The auto-regressive distributive lag (ARDL) model was employed by the authors to analyse the distinct effects of disaggregated renewable and non-renewable energy consumption on CO₂ emissions. The majority of the increase in CO₂ emissions can be attributed to non-renewable energy sources, specifically coal and natural gas, according to the results. Renewable energy sources produce negligible amounts of CO₂. In a renewable energy system, economic development is demonstrated to contribute to pollution, whereas in a non-renewable energy system, this effect is absent. Both of their research endeavours reach the consensus that renewable energy is the most optimal energy source in Pakistan to mitigate carbon dioxide emissions and sustain ongoing economic expansion.

Leal (2018) analyses the correlation between energy consumption, economic growth, and CO₂ emissions in Australia from 1965 to 2015 using the ARLD method. According to empirical research, an increase in GDP stimulates greater investment in renewable energy sources. However, due to its limitations, green technology has no enduring impact on CO₂ intensity. Consumption of non-renewable energy sources will decline due to the rise in CO₂

emissions. Kang et al. (2019) examined the dynamic relationship between non-renewable energy sources, economic growth, renewable energy consumption, and CO₂ emissions in India from 1965Q1 to 2015Q4 through the use of a time-varying parametric technique and a three-variable VAR model. Utilizing a three-variable VAR model in the context of India, their research demonstrates that both renewable and non-renewable energy consumption are subject to stochastic volatility. The observed correlation appears to conform to the U-shaped EKC that is linked to economic expansion. The impulse response result illustrates a positive correlation between fluctuations in GDP and CO₂ emissions originating from diverse energy sources over distinct time intervals.

AlNemer et al. (2023) examined the correlation between renewable and non-renewable energy sources, per capita GDP, and CO₂ emissions in Saudi Arabia from 1963 to 2020. Their findings suggest that carbon emissions from non-renewable energy sources grow as frequency increases. Non-renewable energy sources are associated with environmental pollution in both the short and long term, despite their role in promoting economic development. On the other hand, the adoption of renewable energy sources led to a significant decrease in carbon emissions and stimulated immediate economic expansion. Wavelet analysis shows that renewable energy may promote economic growth and support environmental sustainability and cleanliness.

The study conducted by Zhang et al. (2023) examined the impact of energy production, specifically diesel, oil, and nuclear, as well as energy consumption, specifically fossil fuel energy consumption and overall energy use, on carbon dioxide levels in China during the period spanning from 1991 to 2020. The research incorporated the utilisation of Qualitative Autoregressive Distributed Lag (QARDL) and Augmented Dickey-Fuller (ADF)

tests. On the other hand, the production of energy from coal, hydrocarbon, and nuclear sources showed a direct relationship with CO₂ emissions. The research findings indicated a positive association between CO₂ emissions and the use of fossil fuel energy, energy imports, and total energy consumption.

Apergis et al. (2023) examined the relationship between CO₂ emissions and the use of renewable and non-renewable energy sources in Uzbekistan from 1985 to 2020, employing the Autoregressive Distributed Lags (ARDL) model. The study showed that using hydropower electricity led to a decrease in per capita CO₂ emissions in both the short and long term. In both the short- and long-run, non-renewable energy sources, including natural gas and oil, have a positive effect on CO₂ emissions per capita. Moreover, it has been found that the utilisation of coal has a positive impact on immediate CO₂ emissions.

2.4.2 Panel Level Studies of Non-renewable Energy Consumption, Renewable Energy Consumption, Economic Growth and CO₂ Emissions Nexus

The above has reviewed the nexus of non-renewable energy consumption, renewable energy consumption, economic growth and CO₂ emissions at the countries level. In the second part of empirical finding will be focusing on the studies of panel countries. A multitude of studies have been undertaken to examine the correlation between the utilisation of renewable and non-renewable energy sources, economic expansion, and CO₂ emissions. For instance, Dogan and Seker (2016) investigated the impact of renewable and non-renewable energy, real income, and trade openness on CO₂ emissions in the case of European Union. The results of the dynamic OLS estimator show that green energy and trade will reduce CO₂ emissions, meanwhile non-renewable energy contributes to CO₂ emissions, by using the data from 1980 to 2012. There is also bidirectional causality between renewable energy and CO₂ emissions, as well as unidirectional causality from real income to CO₂

emissions, CO₂ emissions to non-renewable energy, and trade to CO₂ emissions, as determined by the Dumitrescu-Hurlin non-causality approach. Additionally, Dogan and Seker (2016) examine the relationship between CO₂ emissions and real income, consumption of renewable and non-renewable energy, trade openness, and financial development in the leading renewable energy nations. The findings from FMOLS and DOLS indicate that as renewable energy use, trade openness, and financial development increase, pollution decreases; conversely, increased consumption of non-renewable energy leads to elevated CO₂ emissions. In contrast to the findings of Bulut (2017) and Jebli and Youssef (2015) regarding Turkey and the United States, respectively, both investigations by Dogan and Seker (2016) provide support for the EKC.

Jebli et al. (2016) demonstrated bidirectional correlation from 1980 to 2010 between renewable and non-renewable energy consumption, as well as unidirectional causality from trade to CO₂ emissions and output to renewable energy in 25 OECD nations. They argue that as non-renewable energy usage rises, so do CO₂ emissions, and only trade and renewable energy can reduce CO₂ emissions. This location has confirmed the validity of the EKC hypothesis. Souza et al. (2018) conducted a study that investigates the influence of renewable and non-renewable energy consumption, in conjunction with economic growth, on CO₂ emissions in the Southern Common Market (MERCOSUR). The researchers utilised panel data spanning from 1990 to 2014 for their analysis. Their research supports the EKC. A negative correlation has been observed between the utilisation of renewable energy sources and CO₂ emissions, while a positive correlation has been established between non-renewable energy consumption and CO₂ emissions. It has been observed that economic expansion and environmental degradation are correlated.

Using data from emergent economies spanning the years 1990 to 2015, Zafar et al. (2019) investigated the correlation between non-renewable and renewable energy consumption, trade openness, and CO₂ emissions within the EKC framework. In support of the EKC theory, the results indicate that the use of renewable energy sources decreases CO₂ emissions while the use of non-renewable energy sources increases them. The results indicate a long-term causal relationship between the use of renewable energy and the development of GDP. CO₂ emissions, non-renewable energy, and trade openness are all factors that have a causal relationship according to the Granger causality test. Non-renewable energy stimulates economic expansion, whereas renewable energy stimulates GDP growth in the short term. Chen et al. (2019) examined the effects of economic growth, non-renewable energy consumption, and renewable energy consumption on regional China between 1995 and 2012. Contrary to the majority of research findings, the inverted U-shaped EKC theory was not supported in central and western China and was only marginally supported in the eastern region. Central region CO₂ emissions are significantly reduced by non-renewable energy use, in contrast to the western and eastern regions. CO₂ emissions are negatively impacted by the use of renewable energy sources in the western and central regions, but the effect is negligible and inconsequential in the central region.

Destek and Aslan (2019) devoted their research exclusively to examining the correlation between the utilisation of specific renewable energy sources and the release of carbon dioxide emissions within the G-7 countries. Their results indicate that higher utilization of hydroelectricity plays a crucial role in decreasing CO₂ emissions in Italy and the United Kingdom, whereas solar energy contributes significantly to reducing CO₂ emissions in France and Italy. They also stated that hydroelectricity is the optimal renewable energy source for G-7 nations to address increasing environmental degradation.

Araby et al. (2019) examines how renewable and non-renewable energy sources, along with economic growth, affect CO₂ emissions in Euro Mediterranean countries. Analysed data from 2002 to 2016 using the Generalized Least Square estimator revealed that coal has a notable beneficial effect on CO₂ emissions linked to economic growth and electricity production, whereas renewable energy has a contrary influence. Bekun et al. (2019) collected yearly data from 1996 to 2014 to investigate the correlation among CO₂ emissions, resource rent, and the consumption of renewable and non-renewable energy in 16 European Union countries. The results indicate that the utilization of non-renewable energy sources and economic development contribute to CO₂ emissions, whereas the consumption of renewable energy decreases CO₂ emissions. Bilan et al. (2019) discovered that economic growth had a positive impact on the increase in renewable energy consumption among countries aspiring to join the EU between 1995 and 2015. Research in Europe found that non-renewable energy contributes to environmental damage, whereas renewable energy helps reduce CO₂ emissions.

Alqarah (2020) studied the non-linear impact of economic growth and energy consumption on CO₂ emissions in 30 European countries from 2000 to 2018. The panel smooth transition regression (PSTR) model indicates that when economic growth first rises, environmental degradation also grows, but subsequently reduces once a certain level of growth is achieved, aligning with the EKC hypothesis. Radmehr et al. (2021) utilized panel spatial simultaneous equations models with a generalised spatial two-stage least squares (GS2SLS) method to examine the tripartite relationship among economic development, CO₂ emissions, and renewable energy consumption in EU countries from 1955 to 2014. Empirical studies suggest that economic growth has a more pronounced spatial link compared to CO₂ emissions and renewable energy consumption. The data indicates bidirectional correlation

between economic growth and CO₂ emissions, as well as between economic growth and renewable energy consumption. However, there is only unidirectional causality between economic growth and renewable energy consumption.

Nathaniel and Iheonu (2019) analysed the effect of renewable and non-renewable energy consumption on CO₂ emissions in 19 African nations for the period of 1990 to 2014. It was determined that non-renewable energy sources resulted in an increase in CO₂ emissions, whereas renewable energy sources had a negligible impact on CO₂ emission reduction. A unidirectional causal relationship was observed, wherein both renewable and non-renewable energy sources were found to have an impact on CO₂ emissions. The study conducted by Adams and Nsiah (2019) investigates the relationship between renewable and non-renewable energy sources and CO₂ emissions in a sample of 28 Sub-Saharan African nations spanning the years 1980 to 2014. In the short run, there is a significant positive correlation between non-renewable energy and CO₂ emissions. Long-term CO₂ emissions are produced by both renewable and non-renewable energy sources, as demonstrated by the estimation methods of Fully Modified OLS and GMM.

Vural (2020) used advanced panel cointegration methodologies to investigate the relationship among CO₂ emissions, trade, renewable energy, and non-renewable energy in eight Sub-Saharan African countries spanning the period from 1980 to 2014. The results indicate that the rise in CO₂ emissions may be attributed to the utilisation of non-renewable energy sources and trade, whilst the decline in CO₂ emissions can be attributed to the adoption of renewable energy sources. The selected nations serve as substantiation for the EKC framework. An investigation was carried out by Awodumi and Adewuyi (2020) to analyse the impacts of non-renewable energy sources on carbon emissions and economic

development in the most significant oil-producing nations of Africa from 1980 to 2015. This study employs the NARDL methodology. The research undertaken in Nigeria and Gabon illustrates a positive transition from the utilisation of non-renewable energy sources to economic progress, which subsequently leads to a decline in carbon dioxide emissions. Diverse effects on CO₂ emissions may result from the adoption of renewable energy sources and the modification of non-renewable energy usage in a positive direction, contingent upon the time period and energy source in question.

Banday and Aneja (2018) conducted a study that examines the correlation between economic development, CO₂ emissions, energy consumption, and energy consumption in the G7 nations from 1971 to 2014. Their analysis suggests that energy plays a positive and important role in contributing to economic growth, as higher levels of economic growth led to increased demand for energy. There is a one-way causal relationship from economic expansion to CO₂ emissions, which results in a decline in environmental quality through negative externalities affecting community health. Banday and Aneja (2020) expanded their study to include the BRICS countries and found that there is a one-way relationship from economic growth to CO₂ emissions in India, China, Brazil, and South Africa, whereas no such relationship exists for Russia. Evidence of the feedback theory is found in China and Brazil, the growth hypothesis in Russia, the conservation hypothesis in India, China, Russia, Brazil, and South Africa, and the neutrality hypothesis in India, China, Russia, Brazil, and South Africa.

Saidi and Omri (2020) studied the influence of renewable energy on CO₂ emissions and economic growth in 15 countries with high renewable energy consumption. The findings from the FMOLS analysis show that improved renewable energy efficiency leads to

economic growth and reduced CO₂ emissions. The VECM Granger causality test reveals a mutual causal relationship between economic growth and renewable energy, as well as between economic growth and CO₂ emissions in both short and long terms. However, there is no causal link found between CO₂ emissions and renewable energy. Fatima et al. (2020) employed generalized technique of moments, random effects, and fixed effect regression models to study the significance of renewable and non-renewable energy in connection to CO₂ emissions in high emitter countries. They discovered that higher income levels lead to an increase in the variety of energy sources used, which in turn contributes to environmental issues due to the use of non-renewable energy.

The study conducted by Adeboya et al. (2023) investigated the temporal relationship between economic growth, renewable and non-renewable energy utilisation, and CO₂ emissions in the BRIC countries. Quarterly data spanning from 1990/Q1 to 2019/Q4 was utilised. Their study's wavelet coherence analysis showed a strong and positive relationship between CO₂ emissions and economic development. However, this connection deteriorated with time for Russia and South Africa. Coal energy utilization showed a significant and direct correlation with CO₂ emissions in all BRICS nations. Natural gas energy consumption displayed a strong and positive co-movement with CO₂ emissions in Brazil, India, and China, while the association was weaker yet still positive in Russia and South Africa. A notable and positive correlation was observed between oil energy consumption and CO₂ emissions in Brazil, India, and China. However, there were marginal variations in this relationship in Russia and South Africa. The utilisation of geothermal and hydro energy exhibited a marginally positive correlation with CO₂ emissions, although variations in this correlation were observed in data specific to each country.

Voumik et al. (2023) performed research in G7 nations to evaluate how different energy sources impact CO₂ emissions from electricity and heat generation. The study used several statistical methods such as quantile regression, generalized technique of moments, random effects, and fixed effects. The results showed a significant increase in CO₂ emissions while generating electricity from coal and gas, regardless of the technology used. Coal-fired power stations were recognized as having a more significant environmental effect compared to other types of emissions. Oil coefficients had a negative influence on environmental deterioration and were statistically significant in all approaches except quantile regression. Hydroelectric and renewable energy generation significantly decreased CO₂ emissions in all regression models. Nuclear energy was shown to have a positive influence on the environment, with coefficients showing significance in the generalized method of moments and the final quantile.

Kocak et al. (2023) analysed the impact of electricity generated from various sources on energy poverty and greenhouse gas emissions in low-, middle-, and high-income nations using yearly data. Their research using the generalized technique of moments showed that electricity produced from renewable and hydro sources has a substantial role in decreasing both greenhouse gas emissions and energy poverty.

Zhang et al. (2023) conducted an investigation into the correlation between the adoption of renewable energy sources, consumption of non-renewable energy, carbon emissions, and economic development in a group of emergent Asian countries including China, India, Bangladesh, Japan, South Korea, and Singapore. They employed panel autoregressive moving average (ARMA) estimation methods covering the years 1975 to 2020. The study shown that the use of non-renewable energy resulted in a significant

increase in long-term carbon emissions, whereas the utilisation of renewable energy considerably decreased long-term carbon emissions. Consistent with the N-type EKC hypothesis, environmental degradation was found to be significantly influenced positively by GDP and GDP³, but significantly negatively impacted negatively by GDP². These results were observed in the selected developing countries. According to the research findings, India and Bangladesh lack an EKC, while Japan and South Korea exhibit an inverted U-shaped EKC, and China and Singapore possess a bell-shaped EKC, respectively.

Amin and Song (2023) conducted comparative research on the relationship between economic development, renewable and non-renewable energy consumption, urbanization, trade, and CO₂ emissions in South and East Asian nations from 2000 to 2018. Their study uncovered a correlation between the utilisation of non-renewable energy sources and economic growth with the continuous release of CO₂ emissions in South Asia. However, the implementation of trade and the adoption of renewable energy sources contributed to a temporary decrease in CO₂ emissions. It has been demonstrated that economic growth, the use of non-renewable energy sources, industrialization, and commerce all contribute to an increase in East Asian CO₂ emissions over the short and long term. It was observed that the use of renewable energy sources reduced CO₂ emissions.

Voumik et al. (2023) conducted a study to investigate the simultaneous and enduring effects of fossil fuels, nuclear energy, renewable energy, and renewable energy on CO₂ emissions in the countries comprising the South Asian Association for Regional Cooperation (SAARC) between 1982 and 2021. An analysis was conducted on the explanatory variables associated with the EKC concept. According to the study, the EKC theory is inapplicable in the SAARC region. An inverse U-shaped quadratic relationship was observed between GDP

and environmental contamination. The research findings indicate that the primary driver of environmental degradation in SAARC is the consumption of fossil fuels. It also demonstrated that nuclear and renewable energy sources may contribute to long-term pollution reduction.

The study conducted by Wang et al. (2023) examined the interplay between economic development, renewable energy utilisation, and non-renewable energy consumption in seven Northeast Asian countries over the period of 1970 to 2020. Research showed that using renewable energy greatly reduces long-term CO₂ emissions, whereas using non-renewable energy dramatically increases long-term CO₂ emissions. FMOLS analysis showed that GDP and GDP³ have a large positive impact on CO₂ emissions, whereas GDP² has a significant negative impact on CO₂ emissions. This confirms the N-shaped Environmental Kuznets Curve assumption within the chosen nations.

2.4.3 ASEAN Studies of Non-renewable Energy Consumption, Renewable Energy Consumption, Economic Growth and CO₂ Emissions Nexus

Finally, the empirical will be mentioned on the studies of ASEAN countries in relation of renewable and non-renewable energy used as well as economic growth on CO₂ emissions. There are still limited and only few studies had been done for the ASEAN countries or regions. For instance, Chandra and Tang (2013) examine the impact of transportation energy consumption, foreign direct investment, and income on CO₂ emissions in ASEAN-5 countries from 1971 to 2008, noting that economic development is a major contributor to CO₂ emissions in the region. However, throughout this region, particularly in Indonesia, Malaysia, and Thailand, the EKC hypothesis is not validated. Based on the results of Granger causality, there is bidirectional causality between economic growth and CO₂ emissions in Indonesia and Thailand, as well as bidirectional causality between

transportation energy consumption, FDI, and CO₂ emissions in Thailand and Malaysia. However, there is unidirectional causality from GDP to CO₂ emissions in Malaysia.

Heidari et al. (2014) used panel smooth transition regression (PSTR) to investigate the relationship between economic growth, CO₂ emissions, and energy consumption for five ASEAN countries from 1980 to 2008. The findings depict that CO₂ emissions rise with economic growth in contrast with the trend of the second regime. The results also indicate that energy consumption during the first or second regime is associated with a rise in CO₂ emissions. Overall, these findings provide support for the Environmental Kuznets Curve (EKC) curve. Zhu et al. (2016) used panel quantile regression to analyse the impact of foreign direct investment (FDI), economic growth, and energy consumption on CO₂ emissions in the ASEAN since 1981. The research demonstrates that FDI has an adverse effect on CO₂ emissions. Furthermore, at higher quantiles, energy consumption is shown to contribute to CO₂ emissions. The study also highlighted that increasing economic growth and population size can help high-emission countries to reduce CO₂ emissions. Unlike Chandra and Tang (2013), who found significant evidence to support EKC for ASEAN countries, this study found little evidence to support EKC for ASEAN countries. Nonetheless, increasing trade openness can help both low and high-emission countries in cutting CO₂ emissions.

In addition, from 1990 to 2016, Nathaniel and Khan (2020) investigate the impact of renewable and non-renewable energy consumption, economic growth, and urbanization on ASEAN nations' ecological footprints, using the trade as a control variable. The results indicate that economic factors, trade activities, and the use of non-renewable energy sources are significant contributors to environmental issues. Additionally, the Granger causality test

reveals a unidirectional causal relationship, namely from urbanisation to the use of non-renewable energy in ASEAN nations. In their study, Anwar et al. (2020) use the Method of Moments Quantile Regression to analyse the influence of renewable and non-renewable energy consumption on the assessment of the relationship between energy, income, and the environment in ASEAN nations over the period spanning from 1990 to 2018. It has been shown that the utilisation of non-renewable energy sources leads to an increase in CO₂ emissions across all quantiles, whereas the use of renewable energy sources results in a reduction in CO₂ emissions across all quantiles. The findings derived from the FMOLS, DOLS, and FE-OLS methodologies indicate a positive correlation between non-renewable energy consumption and CO₂ emissions, while a rise in renewable energy consumption is associated with a decrease in CO₂ emissions.

An investigation was carried out by Adeel-Farooq et al. (2020) to examine the correlation between methane emissions and economic growth in six ASEAN countries over the period of 1985 to 2012, with respect to the EKC hypothesis. The research employed sophisticated statistical techniques to validate the hypothesis that energy consumption raises methane emissions while economic expansion decreases them, thereby providing support for the EKC. Hanif et al. (2022) conducted an analysis of the impact of renewable and non-renewable energy, economic expansion, and globalisation on CO₂ emissions in the ASEAN-6 countries between 1995 and 2020. The study employed the EKC hypothesis as its theoretical framework. The results of the CS-ARDL estimate demonstrate a noteworthy correlation between globalisation and environmental degradation and non-renewable energy. Conversely, renewable energy exhibits a positive association with the enhancement of environmental quality within ASEAN member states. Furthermore, the results substantiate the concept of the EKC within the chosen economies. As a result, the majority

of inquiries have been carried out along a linear trajectory and have yielded conflicting conclusions regarding the concept of the EKC.

Farooq et al. (2020) investigated the EKC hypothesis about the correlation between methane emissions and economic growth in six ASEAN countries. The study employed sophisticated statistical techniques to validate the applicability of the EKC concept to methane emissions. Economic growth decreases methane emissions, whereas energy use raises them. Hanif et al. (2022) employed the Environmental Kuznets Curve (EKC) hypothesis to examine the influence of economic expansion, globalisation, and the use of renewable and non-renewable energy sources on CO₂ emissions in the ASEAN-6 countries from 1995 to 2020. The results obtained from the CS-ARDL estimate indicate a correlation between globalisation and non-renewable energy in terms of environmental degradation. On the contrary, renewable energy is associated with the enhancement of environmental conditions within the ASEAN countries. Furthermore, the results offer empirical evidence in favour of the EKC as it pertains to the selected economies. Considerable research has been dedicated to linear analysis, yielding inconclusive results regarding the EKC hypothesis.

The impacts of renewable energy, tourism, foreign direct investment, and income on CO₂ emissions in six ASEAN countries were investigated by Pata et al. (2023) via the lens of the EKC hypothesis. The research examined the data from 1995 to 2018 utilising the Dumitrescu-Hurlin panel causality test and the panel ARDL estimator. The results suggest that the long-term income elasticity is relatively diminished in comparison to the short-term, thus providing further support for the validity of the EKC hypothesis. The use of renewable energy sources has shown a short-term reduction in carbon emissions, although its impact on long-term environmental quality remains inconsequential.

2.5 Concluding Remarks

By consulting the extant body of literature, a multitude of scholarly investigations have examined the interdependence between renewable and non-renewable energy sources, economic expansion, and CO₂ emissions in diverse regions and countries. However, each country and region exhibit distinct characteristics stemming from diverse resource requirements and economic structures. Scholars have actively participated in deliberations about the difficulties presented by non-renewable energy sources, insufficient efforts towards renewable energy, and economic expansion, all of which contribute to the deterioration of the environment, specifically in relation to the concentration of CO₂ emissions. It is crucial to do further study on this topic in order to formulate pragmatic strategies for mitigating emissions and jointly attaining net-zero emissions by the year 2050, all the while fostering sustainable economic development. Although numerous studies have investigated the effects of renewable and non-renewable energy sources on CO₂ emissions, there remains a scarcity of research that explores the complex interrelationships among these variables. It is important to emphasise the non-linear relationship between energy sources and CO₂ emissions, especially within the ASEAN-5 area.

Furthermore, various approaches have been utilised in previous research to analyse the impact of economic expansion, consumption of renewable and non-renewable energy sources, and carbon dioxide emissions. The structural VAR approach, Granger causality, the VECM regression model, Panel Smooth Transition Regression, Fully Modified Ordinary Least Squares, Dynamic Ordinary Least Square, and Wavelet Coherence Analysis are the methodologies included in this list. This study employs a non-linear approach to perform a regression analysis on the correlation between the consumption of renewable and non-renewable energy sources and CO₂ emissions. In particular, the panel non-linear ARDL

model is employed for this objective. This methodology allows for the investigation of various parameter disruptions, encompassing both positive and negative impacts, on the variables being examined within the countries being examined.

In summary, the majority of the literature reviewed indicates that an increase in non-renewable energy consumption and economic growth is associated with higher greenhouse gas emissions. Conversely, renewable energy and economic growth have the potential to mitigate CO₂ emissions, influencing environmental improvements across various nations and regions, driven by economic characteristics and market demand. The findings regarding the EKC hypothesis vary across studies, particularly in the case of ASEAN. Some studies support the existence of the EKC hypothesis, while others contradict it. In general, most research suggests that renewable energy can help alleviate environmental issues, in contrast to non-renewable energy consumption, which tends to contribute to environmental crises. Nevertheless, conflicting findings persist, especially concerning the inverted U-shaped EKC hypothesis at different levels, including the country level, panel level, and within the ASEAN region.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This study aims to investigate the impact of consumption of non-renewable and renewable energy, and economic expansion on CO₂ emissions in the ASEAN-5, based on the EKC hypothesis. To accomplish the aims of this research, the following procedures will be followed: identifying the variables that serve as proxies for non-renewable energy, renewable energy, economic growth, and CO₂ emissions; selecting appropriate timeframes; gathering panel data from all ASEAN-5 members; and determining the appropriate methods for analyzing the linear and non-linear relationships among the variables. Firstly, the data description will be discussed in Section 3.2. Secondly, Section 3.3 will be explained on the model specification and Section 3.4 will mention methodologies of the study including, panel unit root test, panel cointegration tests, pooled mean group estimator and non-linear autoregression distributed lag test. Lastly, the summary of this chapter will be mentioned in Section 3.5.

3.2 Data Description

This research analyses the influence of renewable and non-renewable energy sources, together with economic growth, on CO₂ emissions in ASEAN-5 nations from 1990 to 2020 during a 31-year period. The time range for this analysis was chosen based on the availability of data up to 2020 for non-renewable and renewable energy use, economic growth, and CO₂ emissions. The yearly data is selected to fulfil the study's objectives, which include examining the effects of non-renewable energy consumption, renewable energy consumption, and economic growth on CO₂ emissions in both the short and long term.

Additionally, the study aims to explore the non-linear relationship between energy consumption and CO₂ emissions and evaluate the EKC hypothesis in the ASEAN-5 countries.

The relationship between disaggregated energy consumption, economic growth, and CO₂ emissions in the ASEAN-5 (Malaysia, Singapore, Indonesia, Thailand, and the Philippines) is the subject of this study. The ASEAN-5 countries were chosen for this study because to their large GDP, which is above 2 trillion US\$, surpassing that of India, and their population, which exceeds 600 million, surpassing the population of Europe. Aside from Singapore, almost all ASEAN-5 countries have experienced a rise in CO₂ emissions over the course of recent decades. In addition, the ASEAN-5 nations had a rise in non-renewable energy consumption, with Thailand at 109.603%, Malaysia at 87.018%, Indonesia at 80.069%, the Philippines at 62.464%, and Singapore at 60.707%. Green energy consumption remains low in ASEAN-5 countries. In the Philippines, there was a slight 2.131% growth in the use of renewable energy. This was caused by a decline in the proportion of renewable energy used and an increase in the importation of fossil fuels, specifically oil for transportation and coal for the energy industry. An upsurge in the demand for energy would positively influence economic growth. Strong economic growth, higher income per capita, and population expansion in ASEAN-5 countries will lead to increased energy consumption, resulting in a significant environmental issue caused by rising CO₂ emissions.

The study variables for the ASEAN-region consist of the following: pro-renewable energy consumption expressed in kWh per capita; non-renewable energy consumption represented by kWh per capita; and GDP per capita at constant 2010 US dollars utilised as a proxy for economic growth. The CO₂ emissions are quantified in metric tonnes of carbon

dioxide equivalent (MtCo₂). In order to maximize the robustness of the study's findings and reduce the impact of confounding and extraneous variables, the internal validity will be strengthened through the use of control variables: a trade measure expressed as a percentage of GDP to represent trade, and an urban population measure expressed as the annual number of populations to symbolize urbanization. Each variable's definition and data source are detailed in the table that follows.

In accordance with the findings presented in Table 3.1 and previous research (Jebli & Youssef, 2015; Jebli et al., 2016; Bento & Moutinho, 2016; Zafar et al., 2019; Fatima et al., 2020), the selection of trade as the control variable in this model was motivated by its substantial influence on CO₂ emissions. Although among the ASEAN countries' trade improved tremendously and bringing in load of benefits especially in the area of foreign technology, foreign investment and international trade, but increase in trade will rise the problem of environmental degradation, mainly increase in CO₂ emissions (Nathaniel & Khan, 2020). It depicts that ASEAN gets involved in the trade activities will deteriorate environmental quality. Therefore, it is important to include trade as the determinant of CO₂ emissions in the case of ASEAN-5 countries.

Urbanization is responsible for around 70% of the energy associated with global CO₂ emissions, according to the IEA (2017). The ASEAN population was at 700 million in 2021, and the countries in the area are urbanizing at a faster pace. Ali et al. (2019) said that urbanization influences CO₂ emissions in both developed and developing nations. The decision to concentrate on urbanization, rather than other demographic categories such as rural or total population, has sparked much debate. It is often accepted that urban regions, which are in the process of developing, tend to be more affluent and consume more energy

than the rural areas from which their population originates. City dwellers, who embrace more energy-demanding lifestyles, thus, contribute to increased levels of CO₂ emissions compared to those living in rural areas. Urbanization will be considered a control variable due to its large impact on CO₂ emissions. Urbanization's influence on CO₂ emissions has been studied by several researchers from different nations or regions, such as Pata (2018), Adams and Nsiah (2019), Lin and Zhu (2019), Altharhi et al. (2021), and Radmehr et al. (2021).

Table 3.1: Definition, Measure Unit and Source of Studied Variables

Variable	Definition	Unit	Source	Sign
CO2	Carbon dioxide emissions that emitted from the combustion of fossil fuels, which include combustion from solid, liquid and gas fuels and gas flaring.	Metric tons of carbon dioxide equivalent	Global Carbon Atlas	
NREC	Fossil fuels consumption per capita that measured as average consumption from coal, oil and gas per person.	Kilowatt-hour	Our World in Data	Positive
REC	Renewable energy consumption per capita that sum from hydropower, wind, solar, geothermal, wave and tidal as well as bioenergy, but not include biofuels.	Kilowatt-hour	Our World in Data	Negative
GDP	Sum of gross value added by the all-residents producers in economy with product taxes and not including subsidies in value of products.	Constant 2010 US\$	World Development Indicator	Positive
TR	Trade is the sum of exports and imports of goods and services that measure by the share of GDP.	Percentage of GDP	World Development Indicator	Positive

UR	The number of residents living in urban areas as defined by national statistical offices.	Percentage of annually growth	World Development Indicator	Positive
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Notes: CO₂ is CO₂ emissions as dependent variable and independent variables are the NREC as non-renewable energy consumption, REC as renewable energy consumption and GDP as economic growth as well as TR is trade and UR is urbanization as control variables.

3.3 Model Specification

The current study investigates the influence of non-renewable and renewable energy usage, and economic growth on carbon dioxide emissions. Energy consumption and economic expansion are therefore two categories of factors that can be regarded as influencing CO₂ emissions. Therefore, the present investigation examines the subsequent functional form:

$$CO2_{it} = f(NREC_{it}, REC_{it}, GDP_{it}, TR_{it}, UR_{it}, X_{it}) \quad (\text{Equation 3.1})$$

The variables denoted as follows: CO₂ signifies carbon dioxide emissions; NREC and REC denote non-renewable and renewable energy consumption, respectively; GDP and UR represent urbanisation and trade, respectively; X and t represent vectors of additional parameters; and i and t represent the time index and country index, respectively. Equation 3.1 empirical model posits that CO₂ emissions are influenced by factors such as renewable energy consumption, non-renewable energy consumption, economic growth, control variables, and other additional variables.

All the variables will be transformed into the natural logarithm form in order to standardize the data and obtain the elasticities as well as efficient estimates. Therefore, the functional form will be:

$$LCO2_{it} = f(LREC_{it}, LNREC_{it}, LGDP_{it}, LTR_{it}, LUR_{it}, LX_{it}) \quad (\text{Equation 3.2})$$

Next, the above Equation 3.2 is functional form of model will be further regress into the following form of equation:

$$\begin{aligned} LCO2_{it} = & \beta_0 + \beta_1 LREC_{it} + \beta_2 LNREC_{it} + \beta_3 LGDP_{it} \\ & + \beta_4 LTR_{it} + \beta_5 LUR_{it} + LX'_{it}\gamma + \omega_i + \varphi_{it} \end{aligned} \quad (\text{Equation 3.3})$$

where $LCO2$ denotes the natural logarithm of CO₂ emissions, $LREC$ and $LNREC$ indicates the natural logarithm of both renewable and non-renewable energy consumption, respectively, and $LGDP$ reflects natural logarithm of economic growth while the LTR and LUR denote the natural logarithm of trade and urbanization, respectively. Lastly, the natural logarithm of a vector of additional variables is denoted by LX , t is the time, i reveals as the country, ω indicates the country individual effects and ϕ denotes as error term.

The Equation 3.3 will be further regress into dynamic forms of equation and defined as follows:

$$\begin{aligned} LCO2_{it} = & \beta_0 + \beta_1 LCO2_{it-1} + \beta_2 LREC_{it} + \beta_3 LNREC_{it} \\ & + \beta_4 LGDP_{it} + \beta_5 LTR_{it} + \beta_6 LUR_{it} + LX'_{it}\gamma \\ & + \omega_i + \varphi_{it} \end{aligned} \quad (\text{Equation 3.4})$$

In this study, some variables will be considered as control variables that influence on CO₂ emissions. The study will consider trade (TR) (Bento et al., 2016; Dogan & Seker, 2016; Chen et al., 2016; Amri, 2019; Zafar, 2019; Vural, 2020; Fatima et al., 2020) and urbanization (UR) (Shafiei & Salim, 2014; Pata, 2018; Souza et al., 2018; Koengkan et al., 2019; Chen et al., 2019 and Radmehr et al., 2021). These control variables contribute to the study's internal validity by limiting the influence of confounding and other extraneous

variables. This supports the study by making a correlational relationship between the variables of interested.

3.4 Methodology

3.4.1 Panel Unit Root Tests

The initial phase of the investigation will include assessing the stationarity of the series using the Cross Section Augmented Dickey Fuller (CADF) unit root test, a second-generation test that considers cross-section dependency. Pesaran (2007) introduced the CADF unit root test to the literature; it is widely employed in the second iteration of panel unit root testing. The purpose of this test is to analyse panel data utilising the ADF unit root test, which is widely employed in time-series analysis. The CADF statistics record outcomes of country-specific horizontal sections, whereas the Cross Section Im-Pesaran-Shin (CIPS) statistic expands on this by collecting data for the total panel through cross-section averages.

Pesaran employed the cross-sectional augmented Dickey-Fuller (CADF) regression equation, which is given below:

$$\Delta Y_{i,t} - a_i + b_i Y_{i,t-1} + c_i \bar{Y}_{t-1} + d_i \Delta \bar{Y}_t + \varepsilon_{i,t} \quad (\text{Equation 3.5})$$

where $\bar{Y} = \frac{1}{N} \sum_{i=1}^N Y_{i,t}$, $\Delta \bar{Y}_t = \frac{1}{N} \sum_{i=1}^N \Delta Y_{i,t}$ and $\varepsilon_{i,t}$ represents the error term. Pesaran recommends the use of the IPS test's cross-sectional augmented version as following;

$$CIPS = \frac{1}{N} \sum_{i=1}^N CADF_i \quad (\text{Equation 3.6})$$

where the null hypothesis of series is non-stationary and alternative hypothesis of series is stationary of the equation turns into;

$$H_0: \beta_i = 0, \text{ for all } i's$$

$$H_1: \begin{cases} \beta_i < 0, i = 1, 2, \dots, N_1 \\ \beta_i = 0, i = N_1 + 1, N_1 + 2, \dots, N \end{cases}$$

where the rejection decision is based on the test statistic value and the probability value. If the p-value is smaller than 0.05, the null hypothesis is rejected and vice versa. Critical values of the test can be reached from the study of Pesaran (2007).

3.4.2 Panel Cointegration Test

Upon addressing unit root concerns, the subsequent objective is to ascertain the cointegrating relationship among the series. For this purpose, an error-correction-based cointegration test, which accounts for cross-sectional dependence, will be implemented in this study, which is the most recent method developed by Westerlund (2007). A notable characteristic of this approach is its reliance on structural dynamics as opposed to residual dynamics. (Solarin & Al-Mulali, 2018) Therefore, it remains unaffected by the unobserved variable in question. The econometric model can be defined in the subsequent manner.

$$\begin{aligned} \Delta y_{it} = & \delta_i' d_t + \alpha_i y_{it-1} + \lambda' x_{it-1} \\ & + \sum_{j=1}^{pi} \alpha_{ij} \Delta v_{it-j} + \sum_{j=0}^{pi} \lambda_{ij} \Delta x_{it-j} + e_{it} \end{aligned} \quad (\text{Equation 3.7})$$

The speed at which the model's short-term fluctuations are rectified and return to its long-term equilibrium is denoted by α_i , as specified in Equation 3.7. In order to ascertain cointegration, Westerlund (2007) has devised four checks. As indicated below, the initial two evaluations are referred to as group-mean statistics:

At the first stage, Equation 3.7 is estimated with OLS for every unit in panel:

$$\Delta y_{it} = \delta'_i d_t + \hat{\alpha}_i y_{it-1} + \hat{\lambda}' x_{it-1} + \sum_{j=1}^{p_i} \hat{\alpha}_{ij} \Delta v_{it-j} + \sum_{j=0}^{p_i} \hat{\gamma}_{ij} \Delta x_{it-j} + \hat{e}_{it} \quad (\text{Equation 3.8})$$

In Equation 3.8, the p_i which shows lag length is allowed to differ from unit to unit.

Next stage, the error correction parameter p_i is estimated:

$$\alpha_i(1) = 1 - \sum_{j=1}^{\rho t} \alpha_{ij} \quad (\text{Equation 3.9})$$

Parametric method is used to by using the following formula:

$$\tilde{\alpha}_i(1) = 1 - \sum_{j=1}^{\rho t} \hat{\alpha}_{ij} \quad (\text{Equation 3.10})$$

However, the parametric method will lead to deviation in results for small sample, this results in ambiguity when estimating parameters that are autoregressive and influenced by their own deferred values. Thus, the alternative approach called as Kernel approach is need and formulated as following:

$$(\hat{\omega})_{yi}^2 = \frac{1}{T-1} \sum_{j=-M_i}^{M_i} \left(1 - \frac{j}{M_i+1}\right) \sum_{t=j+1}^T \Delta y_{it} \Delta y_{it-j} \quad (\text{Equation 3.11})$$

In the Kernel approach, M_i represents a band with a parameter that expresses the covariance number. The long term variance of Δy_{it} is denoted by $(\hat{\omega})_{yi}^2$. The expression for Δy_{it} is $(\hat{\omega})_{yi}^2/(1)^2$. $(\hat{\omega})_{yi}^2$ represents the long-term variance of the error term. As a result, it

was straightforward to estimate alpha (1) using $\alpha_i(1)\hat{\omega}_{yi}/\hat{\omega}_{yi}$. The following equation is obtained by applying $\hat{\omega}_{yi}$ with Δy_{it} .

$$\hat{u}_{it} = \sum_{j=0}^{\rho t} \hat{\gamma}_{ij} \Delta x_{it-j} + \hat{e}_{it} \quad (\text{Equation 3.12})$$

The $\hat{\gamma}_{ij}$ and $\hat{e}_{it}$ obtained from Equation 3.7 and $\alpha_i(1)$ is semi-parametric Kernel estimator that becomes $\hat{\alpha}_i(1)$.

The final stage of group statistic will be calculated as following:

$$G_t = \frac{1}{N} \sum_{i=1}^N \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \text{ and } G_\alpha = \frac{1}{N} \sum_{i=1}^N \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \quad (\text{Equation 3.13})$$

where SE denotes conventional standard error of $\hat{\alpha}_i$.

The remaining two-panel statistics then investigate whether a cointegrating relationship exists in at least one nation. Panel statistics consist of three phases, the first of which is identical to the first stage of group statistics in Equations 3.7 and 3.8. The second stage includes common error term parameter (α) and $\Delta \tilde{y}_{it}$ and $\Delta \tilde{y}_{it-1}$ which estimates standard error:

$$\hat{\alpha} = \left(\sum_{i=1}^N \sum_{t=1}^T \tilde{y}_{it}^2 \right)^{-1} \sum_{i=1}^N \sum_{t=2}^T \frac{1}{\hat{\alpha}_i(1)} \tilde{y}_{it-1} \Delta \tilde{y}_{it} \quad (\text{Equation 3.14})$$

Calculation of standard error of $\hat{\alpha}$ is expressed as following:

$$SE(\hat{\alpha}) = ((\hat{S}_N^2)^{-1} \sum_{i=1}^N \sum_{t=2}^T \tilde{y}_{it-1}^2)^{-1/2} \quad (\text{Equation 3.15})$$

The $\hat{S}_N^2$ is calculated as follows:

$$\hat{S}_N^2 = \frac{1}{N} \sum_{i=1}^N \hat{S}_i^2 \quad (\text{Equation 3.16})$$

The third stage in panel statistics is the calculation of panel statistics based on following formula:

$$p_t = \frac{\hat{\alpha}}{SE(\hat{\alpha})} \text{ and } p_\alpha = T \hat{\alpha} \quad (\text{Equation 3.17})$$

According to these, the group and panel hypotheses are as follows.

Group Statistics:

$$H_0: \alpha_i = 0 \quad (\text{Cointegration does not exist for } \forall i')$$

$$H_1: \alpha_i < 0 \quad (\text{Cointegration exist for some units, but for some it does not exist})$$

Panel Statistics:

$$H_0: \alpha_i = 0 \quad (\text{Cointegration does not exist for } \forall i')$$

$$H_1: \alpha_i = \alpha < 0 \quad (\text{Cointegration exist for } \forall i')$$

where the rejection decision is based upon the test statistic value and the probability value. The null hypothesis of cointegration among variables is rejected at a significance level of 5% if the computed p-value is less than that threshold. In contrast, the alternative hypothesis of an established cointegration relationship is accepted, and vice versa.

3.4.3 Pooled Mean Group (PMG) Estimator

The mean group estimator is calculated by averaging the individual estimations for each group inside the panel. Pesaran and Smith (1995) said that the mean group estimator provides reliable estimations of the average parameters. Pirotte (1999) states that this estimator offers efficient long-term estimates for high sample sizes. It enables parameters to migrate across groups without taking into account the groupings' possible similarity.

Pesaran et al. (1999) introduced the pooled mean group (PMG) estimator, which permits short-term parameters to vary between groups but enforces long-term coefficients to be the same across nations. The PMG estimator allows for short-run dynamic parameters to vary between countries while maintaining stable long-run coefficients. In contrast to Dynamic OLS (DOLS) and Fully Modified OLS (FMOLS), the PMG estimator emphasises the adjustment dynamic between the short-run and long-run, presuming that the error variances and short-run dynamics are identical. The dynamic specification might vary between nations when short-run coefficients equality is not considered. It is anticipated that the long-run relationship between the consumption of renewable and non-renewable energy, economic growth, and CO₂ emissions will remain consistent across countries. However, it is anticipated that the short-term coefficients will differ.

The good purpose to estimate the long-run equilibrium relationships between variables to be similar across groups is the maximum likelihood (ML) that forecasts the long-run coefficient as well as error-correction coefficients for specific groups, by maximizing respect of γ in following equation:

$$\ell_T(\gamma) = -\frac{T}{2} \sum_{i=1}^N \ln 2\pi\sigma_i^2$$

(Equation 3.18)

$$-\frac{1}{2} \sum_{i=1}^N \frac{1}{\sigma_i^2} (\Delta y_i - \phi_i \xi_i(\theta))' H_i (\Delta y_i - \phi_i \xi_i(\theta))$$

where the $H_i = I_T - W_i(W_i'W_i)^{-1}W_i'$, I_T that denotes as identity matrix of order T , and $\gamma = (\theta', \phi', \sigma')'$.

In testing the hypothesis of slope homogeneity, the study will used Hausman (1978) test. The p -values of Hausman test for PMG estimator that greater than 0.05 significant level will not reject the null hypothesis of long-run homogeneity restriction. In contrast, if the Hausman test p -value is lower than significant level at 5%, the null hypothesis will be rejected.

As this panel study examines with individual rewards in determining the impact of renewable energy consumption, non-renewable energy consumption and economic growth on CO₂ emissions, the wider the time frame of panel knowledge might lead to non-stationary and specious regression. According to Baltagi (2001), non-stationary should be concern in macro panel data with small to moderate N or number of countries with large T or time frame. Hence, in verifying the existence of long-run stable relationship between renewable energy consumption, non-renewable energy consumption and economic growth on CO₂ emissions, each unit roots test at intervals the panel and evaluate cointegration square measure is required before estimating the model. Recently, various procedures in testing unit roots and cointegration, the PMG and MG method with E-views software as well as the advantages of long-run coefficients in panel statistic situation have solved and improved the recognition in investigation that observed.

3.4.4 Panel Non-linear Auto-Regressive Distributed Lag (NARDL) Test

The purpose of this investigation is to validate the non-linear correlation that exists between CO₂ emissions and the utilisation of renewable energy and non-renewable energy. It also attempts to investigate the link between economic growth and CO₂ emissions using the Environmental Kuznets Curve framework. The research will employ the panel NARDL test to ascertain whether positive and negative shocks to energy-growth-environment variables occur in a non-linear cointegration relationship across multiple time periods. The NARDL test was introduced by Shin et al. (2014) and is derived from the linear ARDL model developed by Pesaran and Shin (1999) and Pesaran et al. (2001). Shin et al. (2014) followed the methodology of Granger and Yoon (2002) as well as Schorderet (2003) for the decomposition of stationary variable into positive and negative variations. Thus, the variable X, the two components that is partial sum of variables are shown as following:

$$X^+ = \sum_{j=1}^t \Delta X_j^+ = \sum_{j=1}^t \max(\Delta X_j, 0) \quad (\text{Equation 3.19})$$

$$X^- = \sum_{j=1}^t \Delta X_j^- = \sum_{j=1}^t \min(\Delta X_j, 0) \quad (\text{Equation 3.20})$$

The long-run correlation among the Y and X in non-linear framework will be presented as following:

$$Y_t = \beta^+ X_t^+ + \beta^- X_t^- + \mu_t \quad (\text{Equation 3.21})$$

$$X_t = X_0 + X_t^+ + X_t^- \quad (\text{Equation 3.22})$$

where, β^+ and β^- are the long-run parameters while the X^+ and X^- are the scalars of decomposition partial sums.

By following the Shin et al. (2014), the partial asymmetry cointegration equation can be obtained via including positive and negative shocks of explanatory variable into the standard symmetric equation and the NARDL model shows as following:

$$\begin{aligned}
\Delta LCO2_{t,i} = & \alpha_0 + \sum_{i=1}^n \mu_1 \Delta LCO2_{t-i} + \sum_{i=0}^m \mu_2^+ \Delta LPOS(REC)_{t-i} \\
& + \sum_{i=0}^m \mu_2^- \Delta LNEG(REC)_{t-i} \\
& + \sum_{i=0}^k \mu_3^+ \Delta LPOS(NREC)_{t-i} \\
& + \sum_{i=0}^k \mu_3^- \Delta LNEG(NREC)_{t-i} \\
& + \sum_{i=0}^r \mu_4^+ \Delta LPOS(GDP)_{t-i} \\
& + \sum_{i=0}^r \mu_4^- \Delta LNEG(GDP)_{t-i} + \gamma_0 LCO2_{t-1} \\
& + \gamma_1^+ LPOS(REC)_{t-1} + \gamma_1^- LNEG(REC)_{t-1} \\
& + \gamma_2^+ LPOS(NREC)_{t-1} + \gamma_2^- LNEG(NREC)_{t-1} \\
& + \gamma_3^+ LPOS(GDP)_{t-1} + \gamma_3^- LNEG(GDP)_{t-1} + \omega_t
\end{aligned} \tag{Equation 3.23}$$

In Equation 3.25, m, n, r and k denote as the optimal estimated lag length for the model. The long-run asymmetric effects between economic growth, non-renewable energy consumption, CO₂ emissions, and renewable energy consumption will be determined using the Standard Wald test with the following null and alternative hypotheses:

$$H_0: (\gamma_1^+ = \gamma_1^-); (\gamma_2^+ = \gamma_2^-)$$

$$H_1: (\gamma_1^+ \neq \gamma_1^-); (\gamma_2^+ \neq \gamma_2^-)$$

Rejecting the null hypothesis indicates the presence of asymmetrical impacts from both renewable and non-renewable energy use, as well as economic development, on CO₂ emissions over a long period of time. The long-run elasticity can be computed via:

$$LNREC^+ = \frac{-\gamma_1^+}{\gamma_0}, LNREC^- = \frac{-\gamma_1^-}{\gamma_0}, LREC^+ = \frac{-\gamma_2^+}{\gamma_0}, LREC^- = \frac{-\gamma_2^-}{\gamma_0}, LGDP^+ = \frac{-\gamma_3^+}{\gamma_0}, LGDP^- = \frac{-\gamma_3^-}{\gamma_0}.$$

The current study will combine the methodology of panel NARDL and PMG by Shin et al. (2014) and Pesaran et al. (1999), respectively whereas the panel NARDL model used to achieve the objective of the Study. The reason behind selecting panel NARDL approach to achieve the objectives of this study is due to three superior features over this approach. Firstly, it able to measures the non-linear asymmetries in the data. Secondly, it helps to measure the heterogeneity effect in data and lastly, it is more appropriate with the results of mixed order of integration of variables. According to Chetty (2018), the rule of thumb for employing the model suggest that the data should exhibit a normal distribution and possess stationarity at either $I(0)$ or $I(1)$, or both. It's essential to note that if any variable in the data shows stationarity at $I(2)$, the model cannot be executed.

Munir and Riaz (2019) used NARDL to measure the non-linear effect of energy consumptions on CO₂ emissions in South Asian Countries, Toumi and Toumi (2019) used NARDL to examine the non-linear broadcasting between renewable energy, CO₂ emissions and real GDP and Masibau et al. (2019) employed an identical methodology to investigate the correlation between environmental deterioration, energy consumption, and economic growth. Thus, the panel non-linear ARDL model can be expressed as following:

$$\begin{aligned}
\Delta Y_{it} &= \theta_i ECT_{it} \\
&+ \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta Y_{i,t-j} \\
&+ \sum_{j=0}^{q-1} (\delta_{ij}^{*'+} \Delta X_{i,t-j}^+ + \delta_{ij}^{*-} \Delta X_{i,t-j}^-) + \mu_i + \varepsilon_{it}
\end{aligned} \tag{Equation 3.24}$$

where the $ECT_{it} = \phi_i Y_{i,t-1} - (\beta_i^{'+} X_{i,t}^+ + \beta_i^{-} X_{i,t}^-)$.

3.5 Concluding Remarks

The study will categorise the estimation approach into the subsequent phases. Utilising cross-sectional augmented Dickey-Fuller and cross-sectional augmented Im-Pesaran-Shin unit root tests of the second generation, the stationarity of panel data series from the ASEAN-5 nations is assessed. The data series will progress to the next test after they have achieved stationarity through the first difference. The research will now perform a second-generation cointegration test utilising the error-correction based cointegration test established by Westerlund (2007) to analyse the long-term cointegration relationship between the variables. To accomplish the principal aim of the research, the pooled-mean-group (PMG) estimator is utilised to analyse the influence of economic growth, non-renewable and renewable energy consumption, and CO₂ emissions over both immediate and extended time periods. An inverse relationship between disaggregated energy consumption and CO₂ emissions, as well as between economic growth and CO₂ emissions, was evaluated by the research using a non-linear auto-regressive distributed latency model.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter estimates the long-term, short-term, and non-linear impacts of economic growth and the utilisation of renewable and non-renewable energy sources on CO₂ emissions in the ASEAN-5 countries (Malaysia, Indonesia, Thailand, Singapore, and the Philippines) from 1990 to 2020. The cross-sectional augmented Im, Pesaran, and Shin (CIPS) and cross-sectional augmented Dickey-Fuller (CADF) functions as second-generation panel unit root tests. The Pedroni Panel Cointegration test and the Westerlund (2007) error-correction based cointegration test are examples of first-generation and second-generation panel cointegration tests, respectively, will be used in this study. Second-generation panel unit root tests include the Pooled Mean Group (PMG) estimator and the Auto-Regressive Distributed Lag (ARDL) estimator.

4.2 Cross-sectional Dependence Tests Results

Table 4.1: Results of Cross-sectional Dependence Tests

Variables	Breusch-Pagan LM	Pesaran Scaled LM	Pesaran CD
LCO2	164.9831*** (0.000)	34.6553*** (0.000)	9.0968*** (0.000)
LNREC	233.0438*** (0.0438)	49.8741*** (0.000)	15.0771*** (0.000)
LREC	116.4086*** (0.000)	23.7937*** (0.000)	8.1397*** (0.000)
LGDP	293.4821*** (0.000)	63.3885*** (0.000)	17.1285*** (0.000)
LTR	76.9100***	14.9615***	6.2451***

	(0.000)	(0.000)	(0.000)
LUR	62.7140***	11.7872***	3.2105***
	(0.000)	(0.000)	(0.000)

Notes: Null hypothesis; there is no cross-sectional problem exists in the data. (p-value is larger than 5%). Alternative hypothesis; there is cross-sectional problem exists in the data. (p-value is lower than 5%). The asterisks ***, ** and * denote the significance level at 1, 5 and 10 percent respectively.

Prior to examining the study for linearity and non-linearity, a critical diagnostic test is the cross-sectional dependence test. This test ascertains whether a cross-sectional dependence problem exists or not, which will dictate whether a first-generation or second-generation approach is utilised for the analysis.

Three cross-sectional dependence tests—the Breusch-Pagan LM test, the Pesaran Scaled LM test, and the Pesaran CD test—are applied to the analysed variables in order to ascertain the presence of cross-sectional dependence in each time-series panel data. All variables, including CO2 emission (LCO2) with coefficient value 164.9831, non-renewable energy consumption (LNREC) with coefficient value 233.0438, renewable energy consumption (LREC) with coefficient value 116.4086, economic growth (LGDP) with coefficient value 293.4821, and both control variables including trade (LTR), were determined to be dependent on the outcomes of the Breusch-Pagan LM test and the cross-sectional dependence tests detailed in Table 4.1. All the variables are statistically significant at 0.05 in rejecting the null hypothesis of no cross-sectional problem exists in the data, which the results demonstrate that the data contains cross-sectional dependency.

Secondly, the study employs Pesaran Scaled LM test to check the existence of cross-sectional dependency. The results from Table 4.2 indicates that CO₂ emission with the coefficient value of 34.6553, non-renewable energy consumption with the coefficient value of 49.8741, renewable energy consumption with the coefficient value of 23.7937, economic

growth with the coefficient value of 63.3885 and both trade and urbanization with coefficient value of 14.9615 and 11.7872, respectively. As indicated by the p-values of the Pesaran Scaled LM test results, all variables are statistically significant at the 0.05 level of significance, thus rejecting the null hypothesis that there are no cross-sectional dependency issues among the data. Therefore, the results of the Pesaran Scaled LM test indicate that the variables are cross-sectionally dependent.

Lastly, the Pesaran CD test used to determine the problem of cross-sectional dependence among the data. The outcomes depict that the CO₂ emission with the coefficient value of 9.0968, non-renewable energy consumption with the coefficient value of 15.0771, renewable energy consumption with coefficient value of 8.1397, economic growth with coefficient value of 17.1285, and the control variables of trade and urbanization that show the coefficient value of 6.2451 and 3.2105, respectively. The p-values that were obtained from the analyses suggest that all the variables under investigation are statistically significant at the 0.05 level. This is adequate evidence to reject the alternative hypothesis that the variables are cross-sectionally dependent. Given that the investigated variables are cross-sectionally dependent, as established by all experiments, it is necessary to employ heterogeneous panel techniques with cross-sectional dependence in order to further the investigation. As a result, this investigation employs the cross-sectionally augmented Dickey-Fuller (CADF) and cross-sectionally augmented IPS (CIPS) unit root tests to address both concerns.

4.3 Second Generation Panel Unit Root Test Results

The results of the Breusch-Pagan LM test, Pesaran Scaled LM test, and Pesaran CD test for cross-sectional dependence indicate that the panel contains cross-sectional

dependence across countries. Utilising first-generation conventional panel unit root tests, such as Levin-Lin-Chu (LLC), Im, Pesaran, Shin W-stat (IPS), and PP unit root tests, is not recommended due to their underlying assumption of panel independence. Cross-sectional augmented Dickey-Fuller (CADF) and cross-sectional augmented Im, Pesaran, and Shin (CIPS) unit root tests are utilised in this instance as they are robust to cross-sectional dependence and thus constitute the second generation of unit root tests.

Table 4.2: Results of Second Generation Panel Unit Root Tests

Variables	CIPS		CADF	
	Level	1 st Difference	Level	1 st Difference
LCO2	-2.302**	-4.697***	-2.171	-3.651***
LNREC	-1.500	-4.586***	-1.748	-3.418***
LREC	-3.743***	-5.628***	-2.704**	-5.347***
LGDP	-2.235**	-3.373***	-2.318	-3.713***
LTR	-1.106	-4.813***	-1.191	-3.247***
LUR	-1.578	-5.206***	-1.148	-2.997***

Notes: Null hypothesis; the series contain unit root and non-stationary (p-value is larger than 5%). Alternative hypothesis; the series contain no unit root and stationary (p-value is lower than 5%). The asterisks ***, ** and * denote the significance level at 1, 5 and 10 percent respectively.

According to the outcomes presented in Table 4.2 in relation to the CIPS panel unit root tests, LNREC, LTR, and LUR do not exhibit sufficient significance to reject the null hypothesis that the model is non-stationary and contains a unit root at level. However, LCO2, LREC, and LGDP demonstrate sufficient statistical significance to support the alternative hypothesis that the model is stationary and devoid of a unit root at levels. At the other hands, all the variables including LCO2, LNREC, LREC, LGDP, LTR and LUR become stationary at first difference since the estimated results are statistically significant to accept the alternative hypothesis of stationary and contain no unit root in CIPS unit root test. Furthermore, the results of CADF panel unit root tests show that LCO2, LNREC, LGDP,

LTR and LUR are not significant enough to reject the null hypothesis of non-stationary and contain unit root, except LREC is stationary and contain no unit root at level. In contrast, all the variables namely, LCO2, LNREC, LREC, LGDP, LTR and LUR become stationary at first difference since the outcome depict the statistically significant results to accept the alternative hypothesis of stationary and contain no unit root in CADF unit root test.

The unit root rule suggests that a variable is integrated of order d , denoted as $I(d)$, if it becomes stationary after being differenced d times. In the case of panel unit root tests, both results indicate integration at the first difference, $I(1)$. This means that after the initial differencing, the data will not lead to spurious regression results, preventing the occurrence of apparent correlation between two unrelated panel datasets due to common trends. Given the inherent cross-sectional dependence of the panel data, it is recommended to utilize the LM bootstrap panel cointegration test as a means to approximate the long-run cointegration relationship of the variables.

4.4 Westerlund's (2007) Error Correctional Panel Cointegration Test Results

Table 4.3: Result of Error Correction in Panel Cointegration Test by Westerlund (2007)

Test	<i>t</i> -stat	<i>p</i> – value ^{<i>a</i>}	<i>p</i> – value ^{<i>b</i>}
G_{τ}	-4.6770***	(0.000)	(0.004)
G_{α}	-12.5100	(0.949)	(0.074)
p_{τ}	-9.5170**	(0.001)	(0.037)
p_{α}	-13.5890	(0.698)	(0.144)

Notes: All tests are applied constant and with trend. *a* indicates the tests where *p*-value are asymptotic normal distribution. *b* indicates the test that a *p*-value based on bootstrap method. In this study, 900 bootstrap repeats are used. The asterisks ***, ** and * denote the significance level at 1, 5 and 10 percent respectively.

The model must be devoid of cross-sectional dependence in order to be usable with first-generation cointegration tests, including those proposed by Pedroni Residual, Kao

(1999), and Westerlund (2005) Panel CUSUM. A panel cointegration test, as proposed by Westerlund (2007), is employed in this analysis despite the absence of cross-sectional dependence. When cross-sectional dependence or independence exists, this test is applicable. Also, heterogeneity among the units comprising the panel is permitted by these assays. In comparison to the Panel CUSUM tests developed by Kao (1999), Pedroni Residual, and Westerlund (2005), they are thus more exhaustive.

In order to evaluate the long-run cointegration relationship of the cross-sectional dependency model, the results of a panel cointegration test based on Westerlund's (2007) Error Correctional cointegration are utilized. Based on the Table 4.3, the asymptotic standard distribution of Westerlund test rejects the null hypothesis of no cointegration due to both the group (G_τ) and panel (p_τ) statistics are statistically significant with p – value^a is lower than 0.05 and the value of t -stat -4.6770 and -9.5170, respectively. The outcome of an asymptotic standard distribution remains valid, however, in the absence of cross-sectional dependence within a model. As mentioned previously, the study further used the bootstrap method due to the occurrence of cross-sectional dependency in the model. According to the bootstrap method in Table, the Bootstrap method depict similar outcome with asymptotic standard distribution whereas both the group (G_τ) and panel (p_τ) statistic are statistically significant due to the p – value^b is lower than 0.05. The null hypothesis regarding the absence of cointegration is therefore rejected using the bootstrap method and the asymptotic standard distribution. Long-term co-integration of all variables is confirmed by these results.

4.5 Pooled Mean Group (PMG) Estimator Results

In this section, the panel economic science methodology is discussed. The methodology proposed by Pesaran et al. (1999) for achieving the primary objective of this

study is the pooled mean cluster (PMG) approach. In order to establish the cointegration sort for the autoregressive distributed lag (ARDL) model and to adapt it for the panel configuration, the pooling mean group (PMG) model is employed. This methodology presents a number of benefits when compared to the MG approach. Firstly, it permits variations in short-run dynamic specifications among countries, while guaranteeing identical long-run coefficients. Secondly, it establishes a reasonable expectation that all ASEAN-5 countries will utilise the same long-run coefficient.

Table 4.4: Results of PMG estimator (ASEAN-5)

PMG			
Long-Run (Dependent Variable: LCO2)			
	Coefficient	Std Err.	p-value
LNREC	0.1171***	0.0373	(0.003)
LREC	-0.2947***	0.0042	(0.000)
LGDP	0.7214***	0.0933	(0.000)
LTR	-0.0239***	0.0073	(0.002)
LUR	0.0123*	0.0067	(0.075)
Short-Run (Dependent Variable: LCO2)			
LNREC	-0.1991	0.6710	(0.768)
LREC	-0.0166	0.1209	(0.892)
LGDP	0.0293	0.2868	(0.919)
LTR	-0.1238	0.0861	(0.158)
LUR	0.1535**	0.0708	(0.036)

Notes: The asterisks ***, ** and * denote the significance level at 1, 5 percent and 10 percent, respectively.

The panel-level table presents the long-run and short-run coefficients that establish the relationship between explanatory variables and the dependent variable, as indicated in Table 4.4 of the PMG estimation results. In the long-run, the non-renewable energy consumption (LNREC) has a statistically significant positive impact on CO₂ emissions due

to p -value lower than 0.05. When there is 1 unit increase (decrease) in non-renewable energy consumption, it will cause CO₂ emissions increase (decrease) by 0.1171 unit while the other variables remain constant.

According to the findings, the annual energy consumption of the ASEAN-5 continues to rise, particularly in the case of non-renewable energy sources such as fossil fuel combustion, which contributes to the escalation of environmental issues. For instance, the consumption of coal in installed capacity has been the fastest growing in ASEAN countries, growing by 10.5% annually. This significant growth has brought not only to the rapid economic development but also to the energy-related CO₂ emissions. The outcome of the study is in line with Souza et al. (2019) in the case of MERCOSUR, Zafar et al. (2019) for selected emerging economies countries, Chen et al. (2019) in the case of China 's regional, Araby et al. (2019) in the case of Euro Mediterranean countries, Bekun et al. (2019) in the case of 16 EU countries, Bilan et al. (2019) in the case of candidates and potential candidates of EU membership, Vural (2020) in the case of 8 selected sub-Saharan countries, Nathaniel and Khan (2020) as well as Anwar et al. (2020) in the case of ASEAN countries and Hanif et al. (2022) for ASEAN-6 countries who assert that the use of non-renewable energy sources contributes to environmental degradation.

Furthermore, the PMG estimation result for renewable energy consumption (LREC) indicates a statistically significant negative impact on CO₂ emissions when the calculated p -value is below 0.05. Assuming all other variables remain constant, a one-unit increase (decrease) in clean energy usage is associated with a 0.2947 unit decrease (increase) in CO₂ emissions, as indicated by the coefficient value of renewable energy consumption in the ASEAN-5.

The result indicates that the utilisation of renewable energy sources is crucial for addressing the escalating issue of environmental degradation. The negative impacts of renewable energy consumption also result in technological advancements, specifically in the realm of renewable energy production, being essential for enhancing production quality and reducing production costs. Furthermore, the renewable energy that emitted less CO₂ emissions compared to non-renewable energy able to increase the environmental quality of ASEAN-5. For example, the clean hydrogen is a complementary solution in this region ambitious of climate objectives because when it manufactures results in no CO₂ emissions. The majority of clean hydrogen produced in the 1.5°C scenario for ASEAN aligned with the WETO targeting net-zero emissions globally by 2050 is green-hydrogen which is carbon-free electricity compared to blue hydrogen that producing it fossil fuels, typically natural gas. Therefore, clean hydrogen plays vital role in industry sectors such as iron, steel, aluminium, chemicals and international bunkering shipping. The other study also found the similar outcome such as Jebli and Youssef (2015) in the case of Tunisia, findings of Dogan and Ozturk (2017) show similar results in USA, Bulut (2017) found in the case of Turkey, Leal (2018)'s study shows same estimation in Australia, Dogan and Seker (2016) examined the European Union and its leading renewable energy consumers. Jebli et al. (2016) conducted research on 25 OECD countries. Souza et al. (2019) investigated the Southern Common Market (MERCOSUR). Destek and Aslan (2019) demonstrated that the use of solar energy could reduce CO₂ emissions in France and Italy. Zafar et al. (2019) examined a subset of emerging economy countries. Chen et al. (2019) obtained comparable results for the central and western regions, but the findings became less substantial. Bekun et al. (2019) for the case of sixteen EU countries, Araby et al. (2019) for Euro-Mediterranean countries, and Bilan et al. (2019) for potential and candidate EU members. Environmental quality is

positively impacted by renewable energy, according to eight selected sub-Saharan countries for Vural et al. (2020), fifteen main renewable energy-using countries for Saidi and Omri (2020), ASEAN countries for Anwar et al. (2020), and ASEAN-6 countries for Hanif et al. (2022).

A significant positive correlation (LGDP) between the economic growth of the ASEAN-5 and CO₂ emissions is observed when the p-value is less than 0.05. While the coefficient value shows that 1 unit increase (decrease) in economic growth will increase (decrease) the CO₂ emissions by 0.7214 unit when the other variables are constant.

The findings indicate that ASEAN-5 economic growth will causing the degradation of the environment which at higher economic growth will lead to increase in the demand for pollution that capable to increase the emissions during the periods of economic growth. The rising in growth is unable to balance with the quality of the environment. Krisada et al. (2021) cite an increase in industry-level economic growth necessitating greater consumption of non-renewable energy resources as the primary source of CO₂ emissions in the ASEAN-5 countries. The finding is similar with the studies of Zaidi et al. (2018) Pakistan, Kang et al. (2019) for India, Chandra and Tang (2013) analyse the situation in the ASEAN-5 countries, Heidari et al. (2014) examine the situation in five ASEAN countries, Souza et al. (2019) analyse the situation in the Southern Common Market (MERCOSUR), Araby et al. (2019) analyse the Euro-Mediterranean countries, Fatima et al. (2020) analyse the top eight carbon emitters, Nathaniel and Khan (2020) analyse the ASEAN countries, and Awodumi and Adewuyi (2020) analyse the leading oil producing economies in Africa. In the early stages of EKC, economic growth contributes to CO₂ emissions and vice versa, according to

Alqaralleh (2020). Similarly, Radmehr et al. (2021) found that economic growth is spatially more strongly correlated with CO₂ emissions in the case of twenty-one European countries.

The study's control variables, trade (LTR), demonstrate a statistically significant inverse relationship with CO₂ emissions. The coefficient value signifies that a 0.0239 unit increase or decrease in CO₂ emissions is correlated with a one-unit increase or decrease in trade. The finding of the study is in line with the finding of Dogan and Seker (2016) for the case of top renewable energy countries and for the 25 OECD countries, Jebli et al. (2016) found that it is inconsistent with Vura (2020) for 8 selected sub-Saharan countries that claim the trade is positively impact CO₂ emissions. Lastly, the urbanization (LUR) has an insignificant positive impact on CO₂ emissions when the value of coefficient shows increase (decrease) in 1% of urbanization will increase (decrease) the CO₂ emissions by 0.0123%, but the result is statistically insignificant. The study's findings are consistent with the results of Wang et al. (2018) for the case in Pearl River Delta, Ahmad et al. (2019) for the case in China, Ali et al. (2019) for the case of Pakistan, Mahmood et al. (2020) for the analysis of Saudi Arabia and Adebayo et al. (2021) for the case of Latin American countries.

The research observes that the values of the short-run coefficients for all the variables under investigation do not reach statistical significance. This finding suggests that, with regard to CO₂ emissions, there is no immediate correlation between the utilisation of renewable and non-renewable energy sources and economic expansion. It means in the short run the explanatory variables only emitted an amount CO₂ gas that the level is not concentrated enough to cause environmental problem. Furthermore, it demonstrates that a relatively small proportion of emissions from these nations are incompatible with those of high-emissions nations like the United States and China. Consequently, economic growth

and non-renewable energy consumption impact long-term CO₂ emissions in the ASEAN-5 region in a positive direction, whereas trade and renewable energy consumption have the opposite effect.

4.5.1 PMG of Individual Cross Section Estimation

Table 4.5: Results of PMG of Individual Cross Section Estimation

Countries	Independent Variable				
	LNREC	LREC	LGDP	LTR	LUR
Malaysia	0.4556*** (0.000)	0.5466*** (0.000)	-0.2180** (0.016)	0.1947*** (0.000)	0.9391*** (0.000)
Indonesia	0.7296*** (0.000)	0.3669*** (0.000)	-0.5294* (0.070)	-0.4764*** (0.000)	-1.1151** (0.036)
Thailand	0.6893* (0.065)	0.3843*** (0.000)	-2.4478*** (0.007)	-0.1267*** (0.009)	0.3656*** (0.000)
Philippines	1.4244** (0.035)	0.1592** (0.010)	0.1225 (0.974)	-0.2088 (0.118)	-0.1045 (0.527)
Singapore	-3.7612* (0.063)	0.3287** (0.010)	3.7620 (0.251)	0.3675 (0.315)	-0.1033** (0.036)

Notes: The asterisks ***, ** and * denote the significance level at 1, 5 percent and 10 percent, respectively.

In order to determine the short-run impact of non-renewable energy consumption, renewable energy consumption and economic growth on CO₂ emissions at individual cross-sectional estimation, the full PMG of individual level estimation had been applied. Based on the results of PMG individual cross-section estimation in Table 4.5, Malaysia, all the variables including non-renewable energy consumption and renewable energy consumption as well as trade and urbanization has statistically significant of positive impact on CO₂ emissions with the coefficients of 0.4556 unit, 0.5466 unit, 0.1947 unit and 0.9391 unit, respectively at 5% significant level. Meanwhile, only economic growth has a statistically significant of negative impact towards CO₂ emissions which coefficient depicts 1 unit

increase (decrease) in economic growth will decrease (increase) CO₂ emissions by 0.2180 unit at 5% significant level.

Statistically significant positive effects on CO₂ emissions are observed in the context of both renewable and non-renewable energy consumption in Indonesia. At the 5% significance level, an increase of 1 unit in renewable energy consumption and a decrease of one unit in non-renewable energy consumption will result in a 0.7296 unit increase (decrease) and 0.5466 unit decrease in CO₂ emissions, respectively. Both urbanisation and trade, which are control variables, have a statistically significant negative effect on CO₂ emissions. At the 5% significance level, a 1 unit increase (decrease) in urbanisation and trade will result in a corresponding decrease (increase) of 1.1151 units in CO₂ emissions, respectively. Economic growth is the only variable that demonstrates a negative impact on CO₂ emissions that is not statistically significant, as the computed p-value exceeds 0.05.

Furthermore, at a significance level of 5%, the urbanisation and renewable energy consumption in Thailand have a positive statistical impact on CO₂ emissions. A 1 unit increase or decrease in these variables results in a corresponding 0.3843 unit increase or decrease in CO₂ emissions, and 0.3656 unit decrease. Conversely, statistical evidence suggests that economic expansion and trade have an adverse effect on CO₂ emissions. At the 5% significance level, an increase (decrease) of one unit in trade and economic growth results in a corresponding increase (decrease) of 2.4478 units and 0.1267 units in CO₂ emissions, respectively. As the calculated p-value is greater than 0.05, the non-renewable energy consumption of Thailand does not have a statistically significant positive effect on CO₂ emissions.

Furthermore, it is worth noting that the consumption of both non-renewable and renewable energy in the Philippines exhibits statistically significant positive effects on CO₂ emissions. This is supported by the coefficient values, which indicate that a one-unit increase (or decrease) in non-renewable energy consumption results in a corresponding decrease of 0.1592 units in CO₂ emissions. Conversely, the influence of economic growth on CO₂ emissions is marginally negative and lacks statistical significance, amounting to 0.1225 units. Both control variables exhibit a marginally negative effect on CO₂ emissions of 0.2088 unit and 0.1045 unit, respectively, which is not statistically significant due to the fact that the calculated *p*-value is greater than 0.05.

Finally, Singapore's renewable energy consumption has a statistically significant positive effect on CO₂ emissions, as indicated by the coefficient value of 0.3287 units for every unit increase or decrease in renewable energy consumption at a significance level of 5%. Meanwhile, economic growth and trade also show a positive impact on CO₂ emissions by 3.7620 unit and 0.3675 unit, respectively, but the results are statistically insignificant as the computed *p*-value is larger than 0.05. The urbanization of Singapore shows a statistically significant of negative impact on CO₂ emissions as the coefficient value explained 1 unit increase (decrease) in urbanization will decrease (increase) CO₂ emissions by 0.1033 unit, while the non-renewable energy also depicts a negative impact on CO₂ emissions by 3.7612 units, but the result is statistically insignificant due to computed *p*-value is greater than 0.05.

As shown in Table 4.5, the PMG individual cross-section estimation indicates that non-renewable energy consumption has a positive impact on CO₂ emissions in Malaysia, Indonesia, and the Philippines, but a statistically insignificant positive impact on CO₂ emissions in Thailand and a statistically insignificant negative impact on CO₂ emissions in

Singapore. It is noteworthy that all ASEAN-5 nations demonstrate a statistically significant positive correlation between the adoption of renewable energy sources and short-term CO₂ emissions. Subsequently, the economic expansion of Malaysia and Thailand exhibits a noteworthy adverse effect on CO₂ emissions. In contrast, Indonesia experiences a negligible negative impact on CO₂ emissions, and the Philippines and Singapore demonstrate negligible positive impacts on CO₂ emissions. In relation to the control variables, it is noted that the positive impact of Malaysian trade on CO₂ emissions is statistically insignificant, while the positive impact of Singaporean trade on CO₂ emissions is negligible. On the contrary, Indonesia, Thailand, and the Philippines exhibit adverse impacts on CO₂ emissions; however, the projected result for the Philippines lacks statistical significance. In conclusion, the impact of urbanisation on CO₂ emissions is notably positive in Malaysia and Thailand, but significantly negative in Indonesia and Singapore; the Philippines exhibits a negligible effect.

4.6 Panel Non-Linear ARDL Results

Table 4.6: Results of Non-linear Effects of Panel NARDL (ASEAN-5)

Regressors	Coefficient	Std. Err.	t-Stat	p-value
Long-Run Estimation				
<i>LNREC</i> ⁺	0.4063***	0.1514	2.6844	(0.009)
<i>LNREC</i> [−]	-1.0441**	0.4700	-2.2215	(0.030)
<i>LREC</i> ⁺	-0.2438***	0.0693	-3.5202	(0.001)
<i>LREC</i> [−]	0.2519***	0.0877	2.8736	(0.005)
<i>LGDP</i> ⁺	2.2143***	0.4690	4.7213	(0.000)
<i>LGDP</i> [−]	-1.3333***	0.4475	-2.9796	(0.004)
<i>LTR</i>	0.1164*	0.0674	1.7274	(0.089)
<i>LUR</i>	-0.2663**	0.1014	-2.6262	(0.011)

Short-Run Estimation				
<i>LNREC</i>⁺	0.1021	0.2243	0.455203	(0.650)
<i>LNREC</i>⁻	0.2524	0.5274	0.478671	(0.634)
<i>LREC</i>⁺	-0.0831	0.1132	-0.733631	(0.466)
<i>LREC</i>⁻	0.2051	0.2721	0.753908	(0.454)
<i>LGDP</i>⁺	-0.5037	0.7454	-0.675791	(0.502)
<i>LGDP</i>⁻	0.7968	0.5727	1.391276	(0.169)
<i>LTR</i>	-0.1272*	0.0655	-1.941441	(0.056)
<i>LUR</i>	0.1881	0.1315	1.431344	(0.157)

Notes: *LNREC*⁺ is partial sums of positive change in non-renewable energy consumption, *LNREC*⁻ is partial sums of negative change in non-renewable energy consumption, *LREC*⁺ is partial sums of positive change in renewable energy consumption, *LREC*⁻ is partial sums of negative change in renewable energy consumption, *LGDP*⁺ is partial sums of positive change in economic growth and *LGDP*⁻ is partial sums of negative change in economic growth. The asterisks ***, ** and * denote the significance level at 1%, 5% and 10% respectively.

The study proceed with NARDL because it have satisfied the rule of thumb by which the computed results exhibit a normal distribution and possess stationarity at *I*(1) and the model can be executed. In order to achieve the objective two and three of the study, this study applying the panel form of NARDL approach, which expansion version of ARDL proposed by Shin et al. (2014). The NARDL estimation for the long-run and short-run coefficients for each sample, along with the asymmetric test results, is presented in Table 4.6.

A positive correlation has been observed between positive shocks in non-renewable energy consumption and long-term CO₂ emissions, as indicated by the data in Table 4.6. This relationship is statistically significant at the 0.05 level of significance. Specifically, a one-unit increase in non-renewable energy consumption results in a 0.4063 unit increase in CO₂ emissions. A negative disruption in the consumption of nonrenewable energy, conversely, has a negative impact on CO₂ emissions that is statistically significant at the 0.05

level. Specifically, the results indicate that a one-unit reduction in non-renewable energy consumption corresponds to a 1.0441-unit decrease in CO₂ emissions.

The discovery indicates that non-linear relationships can be observed between the consumption of non-renewable energy sources and the emission of CO₂. The conclusion of the study is that the consumption of non-renewable energy sources contributes to the ASEAN-5's CO₂ emissions, which will exacerbate climate change. This is because the rising in consumption of these fossil fuels will required more on the process of combustion which will emit more greenhouse gas emissions to the atmosphere. The negative shock of non-renewable energy consumption tells that when there is reduction on consumption of dirty energy, the CO₂ emissions will decrease because the combustion of fossil fuels are reduced. The outcome estimation is in line with the study of Akadiri (2021) that tells positive (negative) shock of in non-renewable energy utilization increase (decrease) carbon emissions in India.

Furthermore, it is worth noting that positive shocks to renewable energy consumption have a statistically significant negative effect on CO₂ emissions ($p < 0.05$). This is demonstrated by the coefficient, which states that a 1 unit increase in renewable energy consumption is associated with a 0.2438-unit decrease in CO₂ emissions. Meanwhile, the renewable energy consumption with negative shock shows a positive impact on CO₂ emissions with statistically significant at 0.05, which reduce in 1% unit of renewable energy consumption will increase the CO₂ emissions by 0.2519 unit.

This implies the existence of non-linear impact of renewable energy consumption on CO₂ emissions. Based on the estimated results of long-term NARDL, renewable energy play an important role in mitigating the rising problem of climate change due to high

concentration of CO₂ emissions. This is because the utilisation of green technology to convert inexhaustible resources into clean energy, as opposed to fuel combustion, is required for the consumption of solar, hydro, and wind energy, among others. This proved that renewable energy is more environmentally friendly than when ASEAN-5 focus on rising dependency on clean energy sources will release less carbon. However, if there is low usage in clean energy and still heavily rely on the fossil fuels, the problem of rising CO₂ emissions will increase. Therefore, it is important for ASEAN-5 to focus on renewable energy in order to increase environmental quality and achieve the energy security in the region. The study is supported by Citak et al. (2020) that shows positive (negative) shock of renewable energy able to statistically significant reducing (increasing) the CO₂ emissions in California, USA.

Next, the positive shock of economic growth shows a significant positive impact on CO₂ emissions with due to p-value is lower than 0.05, which increase in 1 unit of economic growth will increase CO₂ emissions by 2.2143 unit. However, the negative shock of economic growth shows a statistically significant negative impact on CO₂ emissions with the coefficient value shows 1 unit decrease in economic growth will decrease the CO₂ emissions by 1.3333 unit.

The study provides further support for the validity of the non-linear correlation between economic growth and CO₂ emissions, and the results indicate that the EKC hypothesis persists over time. In accordance with the EKC theory, it is anticipated that the linear component of GDP contributes to an increase in environmental degradation, whereas the non-linear aspect exerts a negative impact on environmental harm. The coefficients associated with positive and negative economic growth shocks indicate the validity of the EKC theory over the long term. This suggests that, initially, environmental conditions

worsen due to the scale effect at lower levels of economic growth. However, upon reaching a specific threshold of GDP, a compositional effect takes place. This results in a deceleration of the growth process, enabling pollution control initiatives to counterbalance the scale effect and bring about the desired technical effect. Consequently, this discovery affirms the persistence of the EKC hypothesis in the long run.

For the control variables, the trade shows a statistically insignificant ($p\text{-value} > 0.05$) of positive impact on CO₂ emissions whereas increase (decrease) in 1 unit of trade will increase (decrease) CO₂ emissions by 0.1164 unit. While the urbanization shows that it has a significant negative impact ($p\text{-value} < 0.05$) on CO₂ emissions due to the coefficient outcome which 1 unit increase (decrease) in urbanization will decrease (increase) CO₂ emissions 0.2663.

Based on Table 4.6, the study notice that in the short run, all the explanatory variables depict a statistical insignificant result towards CO₂ emissions. This is because the computed coefficient of all the variables portrayed greater than the $p\text{-value}$ of 0.05. In accordance with economic growth, EKC hypothesis do not exist in the short run because of insignificant results. The main reason was because the outcome of coefficients simply reflects the lack of a short run relationship between the consumption of non-renewable and renewable energy, economic growth and both the control variable as well as CO₂ emissions. Therefore, the study can conclude that the non-linear impact between the studied variables did not validate in the short run.

4.7 Concluding Remark

In conclusion, the approach of the second generation is employed for testing purposes. In light of the initial significance of all the independent variables pertaining to CO₂

emissions as determined by the second-generation panel unit root tests, this investigation may employ a second-generation cointegration test, such as the error correctional cointegration test developed by Westerlund (2007), to estimate the long-run cointegration result. The outcomes of the second-generation error correctional panel cointegration test indicate that, in the long run, both the group and panel statistics generated using the bootstrap method are cointegrated. Additionally, the PMG discovered that economic growth and non-renewable energy consumption have a positive influence on CO₂ emissions, whereas renewable energy consumption and trade have a negative effect on long-term CO₂ emissions. In the short term, only urbanisation exhibits a statistically significant negative effect on CO₂ emissions. Finally, in accordance with the non-linear ARDL, the outcomes demonstrate that both non-renewable and renewable energy consumption have a non-linear effect on CO₂ emissions. Likewise, economic growth demonstrates the presence of a non-linear influence on CO₂ emissions, which suggests that the EKC hypothesis holds true for the ASEAN-5 countries over an extended period of time. All explanatory variables exhibit statistically insignificant effects on CO₂ emissions in the short term. Thus, the computed result is inadequate to provide a substantial explanation for the existence of the EKC hypothesis in the short term.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

It is impossible to avoid having a negative impact on the environment when producing and consuming energy, especially in developing economies. As energy sources such as coal, gas, and oil are very important components in developing economies, they act as an "oxygen" to meet energy demands while industries and household consumers consume large amounts of energy, resulting in high concentrations of CO₂ emissions in the atmosphere and contributing to climate change.

In this chapter, the study will consist of four sections, beginning with the current introduction in Section 5.1, followed by summary of the research findings in Section 5.2, and recommendations and policy implications in Section 5.3. The limitations of this study and suggestions for further research will be discussed in Section 5.4, a subsequent section.

5.2 Summary of the Results

The ASEAN-5 region is extremely susceptible to climate change due to its reliance on nonrenewable energy sources, which has led to an increase in CO₂ emissions. CO₂ emissions do not diminish in tandem with economic expansion so long as non-renewable energy sources are utilised. Establishing a linear relationship between the consumption of renewable and non-renewable energy, economic growth, and environmental degradation has been the primary focus of the majority of prior research. Nevertheless, research into the non-linear correlation between the consumption of pure and polluted energy and CO₂ emissions is lacking. Regarding the correlation between economic growth, CO₂ emissions, and the

environment in the ASEAN-5, the extant literature is inconclusive. Diverse pieces of evidence are presented regarding the presence of the EKC hypothesis in these countries.

By examining the short-term and long-term effects of economic growth, non-renewable energy consumption, and non-renewable energy consumption on CO₂ emissions, this study contributes to the existing body of knowledge. By doing so, it transcends linearity and incorporates non-linearity into the analysis. The significance of this approach lies in the fact that it enables two distinct assessments of economic development, non-renewable energy consumption, and renewable energy consumption in relation to CO₂ emissions. In the ASEAN-5, what is the relationship between the use of renewable and non-renewable energy sources, economic growth, and CO₂ emissions? In the ASEAN-5 countries, what is the non-linear correlation between the consumption of non-renewable and renewable energy, economic growth, and CO₂ emissions? In this instance, does the EKC hypothesis exist?

This research covers a 31-year period from 1990 to 2020. This study utilized various empirical panel data series approaches to analyze the research sample. The study utilized the PMG and Panel NARDL research methodologies. The PMG estimator is employed to estimate the linear short-term and long-term effects in order to achieve the first aim. The study shows that the usage of non-renewable energy sources and economic development would lead to an increase in CO₂ emissions due to the rapid rise of fossil fuels, which directly support economic expansion. Renewable energy sources including solar, wind, and hydro power assist decrease CO₂ emissions by not emitting carbon dioxide. Economic expansion is a substantial element contributing to short-term environmental degradation, but both types of energy have no immediate impact on CO₂ emissions.

The NARLD panel was utilised to analyse the non-linear correlation between non-renewable and renewable energy consumption and CO₂ emissions, with the intention of fulfilling the secondary objective of the study. Increased consumption of polluting energy sources results in elevated levels of CO₂ emissions; conversely, a reduction in consumption would ultimately cause a decline in CO₂ emissions. The research establishes a definitive and causal connection between the increasing utilisation of fossil fuel energy sources and the consequent escalation in CO₂ emissions. Reducing the utilisation of renewable energy sources will result in an escalation of environmental issues in the future, whereas increasing their application would effectively alleviate environmental degradation. Proximate statistically, the outcomes do not have any significant implications. Therefore, a decrease in CO₂ emissions could occur as a consequence of increased utilisation of renewable energy sources, or conversely. This segment emphasised the importance of renewable energy sources in mitigating CO₂ emissions from the ASEAN-5 countries and cautioned against the adverse consequences of relying solely on non-renewable energy consumption, which could result in sustained environmental degradation.

The panel NARLD was utilized to analyse the non-linear correlation between economic growth and CO₂ emissions in ASEAN-5 countries, serving as the study's third goal. According to research conducted by NARDL, an increase in economic growth is associated with a concomitant escalation in CO₂ emissions. A contraction in economic growth, on the other hand, causes a continuous decrease in carbon dioxide emissions. In the immediate term, economic progress has a little effect on CO₂ emissions. It is hypothesised that the existence of the EKC is transitory, as environmental conditions deteriorate at lower levels during the initial phases of economic expansion due to the scale effect. A compositional effect emerges once GDP above a specific threshold. As a result, the growth

process decelerates, enabling pollution control programs to counterbalance the scale impact and achieve the desired technical outcome.

5.3 Policy Implication

These findings have substantial policy implications. Based upon the findings, several significant indications about the policies for ASEAN-5 countries been directed in the following section.

5.3.1 Encouraging Switch from Fossil Fuels to Renewables

The study suggests that the governments of the ASEAN-5 countries should make major efforts to shift the emphasis from fossil fuel energy ingredients to renewable energy sources to stimulate economic growth and achieve a goal of environmentally friendly and sustainable production growth. This is because both the negative externalities of using fossil fuels for energy and the positive effects of using energy that is better for the environment are getting worse.

5.3.2 Advocating for Government Priority in Green Investments for Energy Transition

This report suggests that the ASEAN-5 countries prioritize growing their clean investment by committing to a realistic vision of green economic growth. The allocation of funds will facilitate the expeditious advancement and implementation of renewable energy technologies and capabilities within the renewable energy sector. Increased investment will be able to not only sustain progress and reduce environmental degradation, but also stimulate employment and the activities sector. Additional incentives and benefits resulting from investments in renewable energy should be provided to businesses and industries that create and utilize renewable energy. To boost effectiveness, efficiency, and sustainability, these

expenditures could include the installation of additional solar and wind power plants, the imposition of higher carbon levies on fossil fuels, and the prioritization of hydropower facility maintenance. This will improve the economic growth of the countries and create new employment opportunities in the energy industry.

5.3.3 Highlighting Government and NGO Roles in Communication, Education, and Public Awareness (CEPA) for Energy Awareness

The study recommends that governmental and non-governmental organizations in the ASEAN-5 countries increase public knowledge on environmental issues and renewable energy. It also advocates enhancing the importance of practicing the energy conservation and the use of low-carbon energy equipment through communication and education within the local community. Implementing the CEPA strategy is crucial for enhancing energy efficiency and decreasing energy intensity. ASEAN-5 countries should provide support for firms involved in research and development to lower CO₂ emissions and decrease the cost of using renewable energy sources in both the short and long run.

5.4 Limitation and Suggestion for Future Research

This study has a number of limitations that will be addressed in this section. The sample data used in this study are first analyzed at the aggregate level. When analyzed collectively, the data cannot be used to compare the distinct impacts of renewable and nonrenewable energy consumption on CO₂ emissions. The more specific the variables of the study or the level of disaggregated analysis of the study, the more robust and specific the empirical finding. However, when a study uses an aggregate panel dataset, this becomes the main constraint.

Based on this limitation, this study suggests that the future research should first endeavour to do disaggregate level analysis for the case of ASEAN countries. This allowed the study to evaluate the CO₂ emission impacts of non-renewable energy sources, such as coal, oil, and gas, with renewable energy sources, such as hydropower, solar power, and wind power. Consequently, by conducting an exhaustive comparative analysis of the consumption of renewable and non-renewable energy sources, the study is in a position to propose a comprehensive policy framework aimed at mitigating carbon dioxide emissions.

The second limitation is that the sample panel dataset employed in this study was 31 years and is considered small from a statistical standpoint. The larger the sample size, the greater the reliability of the empirical result. However, when a smaller sample size is utilized, this becomes the primary limitation.

The future research should increase the amount of panel data over a longer period of time. This is because the larger the sample dataset and period, the larger the sample size that may be generated. To assure the robustness of the empirical findings, it is essential to improve the panel data analysis by adopting a new method, such as panel dynamic threshold regression, which requires more than 200 samples. It is also applicable to all sample nations.

Lastly, this study may be applicable to the circumstances of the ASEAN-5 countries. As each country and region has its own economic background and behavior, not all locations can learn valuable lessons from this discovery. It is hard for the other region to implement the entire ASEAN economic environment in its economy. There are still improvements to be made. Similarly, improvisation requires additional investigation and development.

Therefore, if individual-nation specification is the primary issue of a future study, the panel model can be narrowed into a time series model of analysis. The analysis can be

improved by including additional nations with diverse histories. As a result, the empirical finding and its commentary acquire greater significance, given that each country may experience a unique outcome. This distinction serves as a valuable lesson for other nations pursuing environmental policies.

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APPENDIX

Table 2.1: Summary of Literature Review

Author(S)	Data	Methodology	Finding (s)
Shabbir et al. (2011)	Variables: - Renewable energy consumption - Non-renewable energy consumption - Real GDP - CO₂ emissions Country: Pakistan Period: 1971 to 2010 Type of Data: Time Series	Structural VAR Approach	- Non-renewable energy contributes to CO₂ emissions and worsen economic activity - Increase in renewable energy consumption support economic development and breed of real GDP
Aremu (2014)	Variables: - Energy consumption - CO₂ emissions - Economic growth Country: Nigeria Period: 1981 – 2011 Type of Data: Time Series	- Restricted Error Correction Model (VAR) - Impulsive Response - Granger Causality	- Existence of long run relationship among variables and energy contribute significantly towards economic growth. - Bidirectional causality between energy consumption and economic growth - Unidirectional causality from energy to CO₂ emissions.
Jebli & Youssef (2015)	Variables: - CO₂ emissions - Economic growth - Renewable energy consumption - Non-renewable energy consumption - Trade Country: Tunisia Period: 1980 – 2009 Type of Data: Time Series	- Autoregressive Distributed Lag (ARDL) Bound testing Approach - Vector Error Correction Model (VECM) Granger causality approach	- Unidirectional causality from trade, GDP, CO₂ emissions and non-renewable energy to renewable energy in short run - Renewable energy consumption weakly and negatively impacts CO₂ emissions - EKC hypothesis is not supported

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Long et al. (2015)	Variables: • Renewable energy • Non-renewable energy • CO₂ emissions • Economic Growth Country: China Period: 1952 -2012 Type of Data: Time Series	• Granger Causality Analysis • Static and Dynamic Regression Analysis	• Bidirectional Causality between GDP with CO₂ emissions, coal, gas and electricity consumption • Coal contributes to economic growth and CO₂ emissions • Oil consumption contributes to CO₂ emissions • Hydro and Nuclear power positively contribute to CO₂ emissions
Mbarek et al. (2017)	Variables: • Renewable energy consumption • Non-renewable energy consumption • CO₂ emissions • Economic growth Country: Tunisia Period: 1990 – 2015 Type of Data: Time Series	• Granger Causality Test • VECM regression model	• Bidirectional causality relationship between energy consumption and CO₂ emissions and between CO₂ emissions and renewable energy consumption • Unidirectional causality relationship from energy used to GDP and from CO₂ emissions to renewable energy consumption • CO₂ emissions significant and negative impact on GDP and renewable energy positively impact GDP

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Dogan & Ozturk (2017)	Variables: • Renewable energy consumption • Non-renewable energy consumption • Real income • CO₂ emissions Country: USA Period: 1980 – 2014 Type of Data: Time Series	• Zivot-Andrews unit root test • Clemente-Montanes-Reyes unit root • ARDL model	• Increase in renewable energy consumption will reduce CO₂ emissions • Increase in non-renewable energy will increase CO₂ emissions • EKC hypothesis is not valid
Bulut (2017)	Variables: • Renewable energy production • Non-renewable energy production • CO₂ emissions Country: Turkey Period: 1970 – 2013 Type of Data: Time Series	• Fixed parameter and time-varying parameter estimation methods	• Production of electricity from renewable energy negatively impact CO₂ emissions while electricity production from non-renewable energy positively impacts CO₂ emissions • EKC hypothesis is not valid
Chen et al. (2018)	Variables: • CO₂ emissions per capita • GDP • Renewable energy production • Non-renewable energy Production • Foreign Trade Country: China Period: 1980 – 2014 Type of Data: Time Series	• VECM based Granger Causality Test	• Inverted U-shape Hypothesis is supported in long-run • Short-run bidirectional causality between foreign trade and renewable energy production and between foreign trade and GDP • Short-run unidirectional causality from economic development and foreign trade to renewable energy production

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Zaidi et al. (2018)	Variables: - Disaggregate renewable and non-renewable energy consumption - CO₂ emissions Country: Pakistan Period: 1970 – 2016 Type of Data: Time Series	ARDL Model	- Non-renewable energy such as coal and natural gas as primary emitters of raising level in CO₂ emissions - Renewable energy consumption insignificant impact on CO₂ emissions - Economic growth contributes to pollution in renewable energy model but not in non-renewable energy model
Leal (2018)	Variables: - Renewable energy consumption - Non-renewable energy consumption - Economic growth - CO₂ intensity Country: Australia Period: 1965 – 2015 Type of Data: Time Series	ARDL Model	- Increase in economic growth will increase share of renewable energy - Increase in renewable energy able to reduce CO₂ intensity - Increase in GDP will reduce non-renewable energy

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Kang et al. (2019)	Variables: • Renewable energy consumption • Non-renewable energy consumption • Economic growth • CO₂ emissions Country: India Period: 1965Q1 – 2015Q4 Type of Data: Time Series	• Three-variable Var Model • Time-varying parametric approach • Impulse response	• Stochastic volatility for renewable and non-renewable energy appears to be U-shaped in relations of economic growth • Impulse response of GDP from a positive shock to CO₂ emissions
Erkisi & Celik (2020)	Variables: • Economic growth • Non-renewable energy • CO₂ emissions Country: Turkey Period: 1990 – 2015 Type of Data: Time Series	• Var Granger Causality Analysis • Variance Decompositions	• Unidirectional Causality from non-renewable energy consumption to CO₂ emissions • In second phase, 13.8% of CO₂ emissions caused by non-renewable energy and 2% by economic growth, while in eighth phase, 44% of CO₂ emissions caused by non-renewable energy consumption and 12% by economic growth • Neutrality hypothesis is supported

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Chandra & Tang (2013)	Variables: • Transportation energy consumption • Foreign direct investment • Income • CO₂ emissions Region: ASEAN-5 countries Period: 1971 – 2008 Type of Study: Panel Data	• Multivariate cointegration analysis • Granger causality analysis	• Economic development is key contributor of CO₂ emissions • EKC hypothesis is not valid in Indonesia, Malaysia and Thailand • Bidirectional causality between economic growth and CO₂ emissions in Indonesia and Thailand, between transport energy consumption, FDI and CO₂ emissions in Thailand and Malaysia • Unidirectional causality from GDP to CO₂ emissions in Malaysia
Heidari et al. (2014)	Variables: • Economic growth • CO₂ emissions • Energy consumption Region: Five ASEAN countries Period: 1980 – 2008 Type of Data: Panel Data	• Panel Smooth Transition Regression (PSTR)	• CO₂ emissions increase with economic growth while there is second regime • Energy consumption with first or second regime contribute to raising in CO₂ emissions • EKC hypothesis is supported

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Dogan & Seker (2016)	Variables: - Renewable energy consumption - Non-renewable energy consumption - Real income - Trade Openness - CO₂ emissions Region: European Union Period: 1980 – 2012 Type of Data: Panel data	- Dynamic OLS Estimator - Dumitrescu-Hurlin non-causality approach	- Renewable energy and trade reduce CO₂ emissions - Non-renewable energy contributes to CO₂ emissions - Bidirectional causality between renewable energy to CO₂ emissions - Unidirectional Causality from real income to CO₂ emissions, from CO₂ emissions to non-renewable energy and from trade to CO₂ emissions
Dogan & Seker (2016)	Variables: - Real income - Renewable energy consumption - Non-renewable energy consumption - Trade openness - Financial development - CO₂ emissions Countries: Top renewable energy countries Period: 1985 – 2011 Type of Data: Panel Data	- Fully Modified Ordinary Least Square (FMOLS) - Dynamic Ordinary Least Square (DOLS)	- Increase in renewable energy consumption, trade openness and financial development reduce pollution - Raising in non-renewable energy consumption increase CO₂ emissions - EKC hypothesis is supported

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Jebli et al. (2016)	Variables: • Renewable energy consumption • Non-renewable energy consumption • GDP • International trade • CO₂ emissions Countries: 25 OECD Countries Period: 1980 – 2010 Type of Data: Panel Data	• Fully Modified Ordinary Least Square (FMOLS) estimates • Dynamic Ordinary Least Square (DOLS) estimates	• Bidirectional causality between renewable and non-renewable energy consumption • Unidirectional causality from trade to CO₂ emissions and from output to non-renewable energy consumption • Raising in non-renewable energy consumption increase CO₂ emissions • Trade or renewable energy able to reduce CO₂ emissions • EKC hypothesis is supported
Zhu et al. (2016)	Variables: • FDI • Economic growth • Energy consumption • CO₂ emissions Region: ASEAN Period: 1981 – 2011 Type of Data: Panel Data	• Panel quantile regression approach	• Negative effect from FDI to CO₂ emissions • Energy consumption contribute to CO₂ emissions at higher quantiles • Raising in economic growth and population size able to mitigate CO₂ emissions at high-emission countries • Study found little evidence to support EKC hypothesis

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Banday & Aneja (2018)	Variables: • Energy consumption • Economic growth • CO₂ emissions Region: G7 countries Period: 1971 – 2014 Type of Data: Panel Data	• Pooled Mean Group ARDL Model • Granger Causality testing based on Dumitrescu and Hurlin (2012) and Emirmahmutoglu and Kose's (2011) Approach	• Energy positively and significantly contributes to economic growth, whereas raising economic growth level bring more demand for energy • Unidirectional causality from economic growth to CO₂ emissions, it led to declination of environmental quality in negative externalities via people health
Souza et al. (2019)	Variables: • Renewable energy consumption • Non-renewable energy consumption • CO₂ emissions Region: Southern Common market (MERCOSUR) Period: 1990 - 2014 Type of Data: Panel Data	• OLS regression analysis	• Renewable energy consumption negatively impacts CO₂ emissions • Non-renewable energy consumption positively impacts CO₂ emissions • Economic growth contributes to environmental degradation • EKC hypothesis is valid
Hanif et al. (2022)	Variables: • Globalization • Economic growth • Renewable energy • Non-renewable energy • CO₂ emissions Region: ASEAN-6 countries Period: 1995 - 2020	• CS-ARDL Estimation	• Non-renewable energy and globalization contribute to CO₂ emissions, whereas renewable energy has a positive contribution to environmental quality improvement in ASEAN countries. • EKC hypothesis supported

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Zafar et al. (2019)	Variables: - Renewable energy consumption - Non-renewable energy consumption - Trade openness - CO₂ emissions Countries: Selected emerging economies countries Period: 1990 – 2015 Type of Data: Panel Data	- Morgan Stanley Capital International's (MSCI's) classification - Continuously updated fully modified (CUP-FM) - Continuously Update bias-corrected (CUP-BC) - Vector Error Correction Model (VECM)	- Renewable energy consumption impact negatively towards CO₂ emissions - Non-renewable energy Consumption impact positively towards CO₂ emissions - Long-run Granger causality from renewable energy consumption and GDP to CO₂ emissions - Short-run Granger cause from renewable energy to GDP growth and economic growth - Granger cause non-renewable energy - EKC hypothesis is supported
Destek & Aslan (2019)	Variables: - Disaggregate renewable energy consumption - CO₂ emissions Region: G-7 countries Period: 1991 - 2014 Type of Data: Pane Data	- Augmented Mean Group Estimator - Panel Bootstrap Causality Method	- Increase in hydroelectricity usage significant in mitigating CO₂ emissions for Italy and United Kingdom - Solar energy consumption suitable in mitigating CO₂ emissions for France and Italy - Hydroelectricity is greatest source of renewable energy in reducing environmental degradation

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Chen et al. (2019)	Variables: • Economics growth • Renewable energy consumption • Non-renewable energy consumption • CO₂ emissions Country: China's Regional Period: 1995 – 2012 Type of Data: Panel Data	• FMOLS and OLS estimations	• Non-renewable energy consumption greatly positive impacts CO₂ emissions in central • Renewable energy consumption impacts CO₂ emissions negatively in central and western regions, it becomes weak and insignificant in central region • Inverted U-shaped EKC hypothesis invalid for central and western of China, but valid for eastern region
Araby et al. (2019)	Variables: • Electricity production from renewable energy source • Electricity production from non-renewable energy source • Economic growth • CO₂ emissions Region: Euro Mediterranean countries Period: 2002 – 2016 Type of Data: Panel Data	• Generalized Least Square Estimator	• Economic growth and electricity output from coal positively influence CO₂ emissions • Electricity output from renewable energy negatively impacts CO₂ emissions

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Bekun et al. (2019)	Variables: • CO₂ emissions • Resource rent • Renewable energy consumption • Non-renewable energy consumption Region: 16 EU Countries Period: 1996 - 2014 Type of Data: Panel Data	• Kao test • Panel Pooled Mean Group-Autoregressive Auto regressive distributive lag model (PMG-ARDL) • Panel Causality Analysis	• Non-renewable energy consumption and economic growth positive impact on CO₂ emissions • Renewable energy consumption mitigates CO₂ emissions • Feedback mechanism between economic growth, renewable and non-renewable energy consumption • Feedback causality between natural resources rent and economic rent
Bilan et al. (2019)	Variables: • Renewable energy sources • CO₂ emissions • Economic growth Region: Candidates and Potential candidates of EU membership Period: 1995 – 2015 Type of Data: Panel Data	• Fully Modified OLS (FMOLS) • Dynamic OLS (DOLS) panel cointegration techniques • Vector Error Correction Model (VECM)	• Economic growth contributes to raising in renewable energy consumption • Non-renewable energy consumption positively impacts environmental degradation • Renewable energy mitigating CO₂ emissions

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Nathaniel & Iheonu (2019)	Variables: • Renewable energy consumption • Non-renewable energy consumption • CO₂ emissions Region: 19 African Countries Period: 1990 – 2014 Type of Data: Panel Data	• Augmented Mean Group (AMG) Estimation	• Renewable energy insignificantly mitigating CO₂ emissions • Non-renewable energy led to higher CO₂ emissions • One-way causality from renewable and non-renewable energy to CO₂ emissions
Adams & Nsiah (2019)	Variables: • Renewable energy • Non-renewable energy • CO₂ emissions Region: 28 Sub-Saharan African countries Period: 1980 – 2014 Type of Data: Panel Data	• Fully Modified OLS method • GMM estimation method	• Non-renewable energy is significant and positive relationship towards CO₂ emissions in short-run • Renewable and non-renewable energy contribute to CO₂ emissions
Vural (2020)	Variables: • Output • Trade • Renewable energy • Non-renewable energy • CO₂ emissions Region: 8 Selected Sub-Saharan countries Period: 1980 – 2014 Type of Data: Panel Data	• Second General Panel Cointegration Methods	• Non-renewable energy and Trade positively contributed to CO₂ emissions • Renewable Energy reduces CO₂ emissions • EKC hypothesis is not supported

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Banday & Aneja (2020)	Variables: - Renewable energy consumption - Non-renewable energy consumption - GDP growth - CO₂ emissions Countries: Brazil, Russia, India, China and South Africa (BRIC) Period: 1990 – 2017 Type of Data: Panel Data	Bootstrap Dumitrescu and Hurlin Panel Causality test	- Existence of unidirectional causality from economic growth to CO₂ emissions in India, China, Brazil and South Africa while no causal for Russia - Feedback hypothesis in China and Brazil - Growth hypothesis in Russia - Conservation hypothesis on India, China, Russia and Brazil - Growth hypothesis in South Africa
Saidi & Omri (2020)	Variables: - Renewable energy - CO₂ emissions - Economic growth Countries: 15 major renewable energy used countries Period: 1990 – 2014 Type of Data: Panel Data	- Fully Modified OLS (FMOLS) method - VECM Granger Causality test	- Renewable energy increases economic growth and mitigating CO₂ emissions - Two-way causality between economic growth and renewable energy, between economic growth and CO₂ emissions for short-run and long-run - No causality relation between CO₂ emissions and renewable energy

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Fatima et al. (2020)	Variables: - Renewable energy consumption - Non-renewable energy consumption - Economic Growth - Trade Openness - CO₂ emissions Countries: Top 8 Carbon Emitter countries Period: 1980 – 2014 Type of Study: Panel Data	Generalized Method of Moments, Random Effects and Fixed Effects regression model	Increase in income bring more energy mix, then contributes to environmental degradation through non-renewable energy
Nathaniel & Khan (2020)	Variables: - Renewable energy consumption - Non-renewable energy consumption - Economic growth - Urbanization - Trade - Ecological Footprint Region: ASEAN countries Period: 1990 – 2016 Type of Data: Panel Data	- First- and second-generation unit root and cointegration tests - Augmented Mean Group Estimator - Granger causality test	- Economic growth, trade and non-renewable energy significantly contribute to environmental problem - One-way causality from urbanization to non-renewable energy consumption

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Anwar et al. (2020)	Variables: - Renewable energy consumption - Non-renewable energy consumption - Economic growth - CO₂ emissions Region: ASEAN countries Period: 1990 – 2018 Type of Data: Panel Data	- Method of Moments Quantile Regression - Fully Modified Ordinary Least Square (FM-OLS), Dynamic-OLS and Fixed-Effect-OLS Methods	- Non-renewable energy consumption contributed to CO₂ emissions at all quantiles - Renewable energy consumption reduces CO₂ emissions at all quantiles - Increase in non-renewable energy increase CO₂ emissions but raising in renewable energy consumption mitigate CO₂ emissions - EKC hypothesis is supported
Awodumi & Adewuyi (2020)	Variables: - Non-renewable energy - Economic growth - Carbon emissions Region: Top oil production economies in Africa Period: 1980 – 2015 Type of Data: Panel Data	Non-linear autoregressive distributed lag (NARDL) technique	- Positive change in non-renewable energy consumption towards economic growth, but it reduces CO₂ emissions in Nigeria and Gabon. - Positive change in non-renewable energy consumption contribute to economic growth and effect on CO₂ emissions with mixed cross time and energy type.
AlNemer et al. (2023)	Variables: - Renewable and non-renewable energy sources - CO₂ emissions - GDP per capita Country: Saudi Arabia Period: 1963 – 2020 Type of data: Time Series data	Wavelet Coherence Analysis	- Non-renewable energy sources lead to carbon emission expansion in frequency domain - Non-renewable energy sources indorsed the economic growth across short-and medium-term scales - Renewable energy consumption has an effect on carbon emissions drop and on economic growth in the short-term.

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Alqaralleh (2020)	Variables: • Energy consumption • Economic growth • Environmental degradation Region: Europe Period: 2000 – 2018 Type of Data: Panel data	• Panel Smooth Transition Regression (PSTR)	• Early, economic growth led to environmental degradation, then it reduces the problem when certain growth level has reached. • Supported EKC hypothesis.
Adeel-Farooq et al. (2020)	Variables: • Economic growth • Energy consumption • Methane Emissions • Region: ASEAN • Period: 1985 – 2012 Type of Data: Panel Data	• Mean Group (MG) Technique • Pooled MG (PMG) technique	• Economic growth increase reduces emissions while energy consumption increases methane emissions • EKC hypothesis is supported
Radmehr et al. (2021)	Variables: • CO₂ emissions • Economic growth • Renewable energy Region: 21 Europe countries Period: 1995 – 2014 Type of Data: Panel	• Panel spatial simultaneous equations models with generalized spatial two-stage least squares (GS2SLS) method	• Economic growth stronger spatially correlated than CO₂ emissions and renewable energy consumption • Bidirectional causality between economic growth and CO₂ emissions and between economic growth and renewable energy consumption • Unidirectional causality from economic growth to renewable energy consumption

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Zhang et al. (2023)	Variables: • Energy production (oil, coal and nuclear) • Energy Usage (fossil fuel energy consumption and energy use) • Carbon dioxide Emission Country: China Period: 1991 – 2020 Type of Data: Time Series Data	• Quantile Autoregressive Distributed Lag (QARDL) • Augmented Dickey-Fuller (ADF) test	• Electricity production from oil, coal and nuclear has a positive connection with CO₂ emission • Fossil fuel energy consumption, energy import and energy use also have a positive relationship towards CO₂ emissions
Apergis et al. (2023)	Variables: • CO₂ emissions • Renewable and non-renewable energy Country: Uzbekistan Period: 1985 – 2020 Type of Data: Time Series Data	• Autoregressive Distributed Lags (ARDL) model	• Hydropower energy consumption negatively impacts CO₂ emissions per capita while non-renewable energy consumption has a positive impact on CO₂ emissions per capita both in short and long run • Coal consumption positively impacts CO₂ emission in the short run
Adeboya et al. (2023)	Variables: • CO₂ emissions • Economic growth • Non-renewable • Renewable energy consumption Region: BRIC countries Period: 1990/Q1 – 2019/Q4 Type of Data: Panel Data	• Wavelet Coherence Analysis	• A strong and positive co-movement between CO₂ emission and economic growth • Coal energy consumption is strongly and positively co-moved with CO₂ emissions for all BRICS countries • Oil and nature gas energy consumption is strongly and positively co-moved with CO₂ emissions in Brazil, India and China

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Voumik et al. (2023)	Variables: - Electricity production - Heat production - CO₂ emissions Region: G7 countries Period: 1971 - 2019 Type of Data: Panel Data	- Quantile regression - Generalized method of moments - Random effects and fixed effects.	- Coal-fired power plants have a larger impact on the environment - Oil coefficients have a negative impact on environmental degradation - Hydroelectric and renewable energy production can reduce CO₂ emissions in all regression models - Nuclear energy has a beneficial impact on the environment
Zhang et al. (2023)	Variables: - Renewable energy consumption - Non-renewable energy consumption - Carbon emissions - Economic growth Region: Asian emerging economies Period: 1975 - 2020 Type of Data: Panel Data	Panel Augmented Mean Group (AMG) estimation techniques	- Non-renewable energy consumption significantly increased long-term carbon emissions - Renewable energy consumption significantly reduced long-term carbon emissions - No EKC in India and Bangladesh, an inverted U-shaped EKC in China and Singapore, and an N-shaped EKC in Japan and South Korea
Amin & Song (2023)	Variables: - Economic growth - Renewable and non-renewable energy consumption - Urbanization - Trade - CO₂ emissions Region: South and East Asian countries Period: 2000 - 2018 Type of Data: Panel Data	Comparative approach	- Non-renewable energy and economic growth increase long-term CO₂ emissions in South Asia - Trade and use of renewable energy consumption reduce CO₂ emissions in the short-term - Economic growth, NREC, trade and urbanization increased CO₂ emissions in the short and long run - REC reduce CO₂ emissions

Table 2.1: Summary of Literature Review (Continued)

Author(S)	Data	Methodology	Finding (s)
Voumik et al. (2023)	Variables: • Fossil fuels • Renewable energy • Nuclear energy • CO₂ emissions Region: South Asian Association for Regional Cooperation (SAARC) Period: 1982 - 2021 Type of Data: Panel Data	• Slope Homogeneity Test and Cross-Sectional Dependency (CSD) Test • Augmented Mean Group (AMG) Test	• EKC does not hold in SAARC and a U-shaped quadratic link exists between GDP and environmental pollution • Environmental pollution is caused by fossil fuel, whereas using renewable (REN) and nuclear energy can cut long-term pollution
Wang et al. (2023)	Variables: • Renewable energy consumption • Non-renewable energy consumption • CO₂ emissions, • Economic growth Region: Seven selected Northeast Asian countries Period: 1970 - 2020 Type of Data: Panel Data	• FMOLS technique	• Renewable energy consumption significantly reduces long-term CO₂ emissions • Non-renewable energy consumption significantly contributed to long-term CO₂ emissions • N-shape EKC assumption in selected group of countries
Pata et al. (2023)	Variables: • Renewable energy • Tourism • Foreign direct investment • Income • CO₂ emissions Region: Six ASEAN countries Period: 1995 - 2018 Type of Data: Panel Data	• Panel ARDL estimator • Dumitrescu-Hurlin panel causality test	• Long-run oncome elasticity is lower than the short-run • EKC hypothesis is valid. • Renewable energy reduces carbon emissions only in the short term and has no effect on environmental quality in the long-term.